(1)

ARI Research Note 88-118

Increasing Bradley Fighting Vehicle Effectiveness: Improved Training Approaches and Equipment

Robert L. Rollier, Steven D. Knapp, Donald P. Frederick,
David F. Champion, and Paul R. Roberson
Litton Computer Services Division
Litton Systems, Inc.
and
Margaret S. Salter
U.S. Army Research Institute

for

Contracting Officer's Representative
Seward Smith

Field Unit at Fort Benning, Georgia
Seward Smith, Chief

Training Research Laboratory
Jack H. Hiller, Director

July 1988

United States Army
Research Institute for the Behavioral and Social Sciences

U.S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction of the Deputy Chief of Staff for Personnel

EDGAR M. JOHNSON
Technical Director

JON W. BLADES
COL, IN
Commanding

Research accomplished under contract
for the Department of the Army

Litton Computer Services Division
Litton Systems, Inc.

Technical review by

Robert J. Pleban

NOTICES

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: Unclassified

1b. RESTRICTIVE MARKINGS: --

2a. SECURITY CLASSIFICATION AUTHORITY: --

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE: --

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): --

5. MONITORING ORGANIZATION REPORT NUMBER(S): ARI Research Note 88-118

6a. NAME OF PERFORMING ORGANIZATION: Litton Computer Services Div., Litton Systems, Inc.

6b. OFFICE SYMBOL (If applicable): --

7a. NAME OF MONITORING ORGANIZATION: U.S. Army Research Institute Field Unit at Fort Benning, GA

6c. ADDRESS (City, State, and ZIP Code): P.O. Box 7113, Mountain View, CA 94039-7113

7b. ADDRESS (City, State, and ZIP Code): P.O. Box 2086, Fort Benning, GA 31905-0686

8a. NAME OF FUNDING / SPONSORING ORGANIZATION: U.S. Army Research Institute for the Behavioral and Social Sciences

8b. OFFICE SYMBOL (If applicable): PERI-I

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: MDA903-85-C-0400

8c. ADDRESS (City, State, and ZIP Code): 5001 Eisenhower Ave., Alexandria, VA 22333-5600

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
63744A	795	342	C1

11. TITLE (Include Security Classification): Increasing Bradley Fighting Vehicle Effectiveness: Improved Training Approaches and Equipment

12. PERSONAL AUTHOR(S): Rollier, Robert L.; Knapp, Steven D.; Frederick, Donald P.; Champion, David F.; Roberson, Paul R. (Litton Computer Services Division, (Continued)

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 86/09 TO 87/09	1988, July	62

16. SUPPLEMENTARY NOTATION: Contracting Officer's Representative: Seward Smith

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

BFV silent auxiliary generator
BFV coaxial machine gun mounting pin
BFV transparent cargo hatch
BFV integrated sight unit
(Continued)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Nine issues that affect the combat effectiveness of the Bradley Fighting Vehicle (BFV) are discussed in this report. All of them were selected for development and evaluation work. The general findings for each area indicate the following: (a) a thermal training package can enhance individual and unit capability during limited visibility conditions, (b) a modified range card may be easier to use than the existing BFV cards, (c) an optical range finder can provide the dismount element of the BFV with an accurate, low-cost range estimation tool to aid in employing infantry weapons systems, (d) synthetic thermal barrier materials may be able to prevent combat vehicles from being detected by threat thermal devices, (e) a 25-mm on-board ammunition stowage container can increase survivability of the BFV, reduce loading times, and increase vehicle stowage capacity, (f) a 7.62-mm coaxial machine gun mount pin can virtually eliminate loss of pins and can increase the availability of BFVs, (g) a transparent cargo hatch prototype can be built and installed on BFVs to increase visibility from the squad compartment, allow forward observer tasks to be performed,

(Continued)

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL: Seward Smith

22b. TELEPHONE (Include Area Code): (404) 835-5589

22c. OFFICE SYMBOL: PERI-IJ

DD Form 1473, JUN 86 — *Previous editions are obsolete.*

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

ARI Research Note 88-118

12. PERSONAL AUTHOR(S) (Continued)

Litton Systems, Inc.); Salter, Margaret S. (ARI).

18. SUBJECT TERMS (Continued)

BFV ammunition stowage	Optical range finder
Thermal shielding material	Thermal training
Driver alert system	Range card

19. ABSTRACT (Continued)

and reduce motion sickness and claustrophobia, (h) a proposed silent generator concept can provide a means of ensuring combat readiness by keeping critical BFV combat systems ready for immediate response during silent watch missions, and (i) a driver alert system can allow the BFV commander to wake a sleeping or inattentive driver and alert him to imminent vehicle movement.

FOREWORD

The Army Research Institute for the Behavioral and Social Sciences (ARI) has contributed to a program to define emerging problems and address critical issues affecting the Bradley Fighting Vehicle (BFV). Consistent with that program, this report describes equipment and training modifications and changes intended to improve the combat capability of the BFV. Because the vehicle incorporates advanced weapons systems and sights to be used under limited visibility, special emphasis was given to research that focused on operations under those conditions.

ARI's Fort Benning Field Unit, a division of the Training Research Laboratory, monitored the research. ARI's mission is to conduct research of training and training technology using infantry combat systems and problems as mediums. The research task that supports this mission is 3.4.2., "Advanced Methods and Systems for Fighting Vehicle Training," organized under the "Train the Force" program area. Sponsorship for this research effort is provided by a Memorandum of Understanding (effective 31 May 1983) between the U.S. Army Infantry School (USAIS), Training and Doctrine Command (TRADOC), Training Technology Agency, and ARI, which established how joint efforts to improve BFV tactical doctrine, unit, and gunnery training would proceed.

Feedback from frequent in-process reviews (IPR) and briefings to USAIS and 1st Battalion, 29th Infantry Regiment suggests that the research projects reported here will improve the capabilities of the BFV and its personnel.

INCREASING BRADLEY FIGHTING VEHICLE EFFECTIVENESS: IMPROVED TRAINING APPROACHES AND EQUIPMENT

EXECUTIVE SUMMARY

Requirement:

Litton Computer Services operated under contract to and with guidance from the Army Research Institute for the Behavioral and Social Sciences (ARI) at Fort Benning, Georgia. Litton contracted to develop procedures, equipment, and training to enhance the combat capability of the Bradley Fighting Vehicle (BFV). Specific requirements for this project included improving procedures for conducting tactical surveillance under all visibility conditions, determining whether equipment or training modifications would improve personnel performance, and demonstrating potential solutions to identified problems.

Procedure:

The researchers divided the investigation into two 1-year components--a first-year problem development phase and a second-year testing and evaluation phase. To collect data, the researchers used multiple methodclogies, including literature reviews, on-site observations, man-machine interface analyses, field tests, and evaluation of prototype solutions under experimentally controlled conditions.

Findings:

This 2-year research program identified nine areas where training and equipment modifications were required. Training issues focused on developing a thermal training package and investigating a number of issues related to range estimation. Equipment issues focused on testing a thermal shielding material, developing a procedure for modifying selected integrated sight unit (ISU) controls, designing a standardized range card and a small, inexpensive optical range finder, developing a concept for a silent auxiliary generator, and designing the following: a driver alert system (DAS), an on-board stowage container for 25-mm ammunition, a transparent cargo hatch, and a new mounting pin for the BFV's 7.62-mm coaxial machine gun.

Utilization of Findings:

We are confident that the thermal training package will improve gunner training by addressing such critical variables as sight magnification and polarity, range to the target, and target cover, camouflage, and concealment. The procedure for modification of the controls should enable BFV gunners to

obtain an optimum thermal image more quickly and retain it longer. Further investigation of synthetic materials to protect vehicles, equipment, and personnel against thermal detection has significant potential for increasing security of forces by limiting the effectiveness of thermal sights. The range finder should provide junior leaders with a more accurate means of estimating range, while the standardized range card may simplify the task of making the range card. The driver alert system (DAS) will permit the BFV commander to wake the driver and alert him to imminent vehicle movement. The 25-mm on-board ammunition stowage container should promote survivability, reduce reload time, and increase vehicle stowage capacity. The design for a transparent cargo hatch should enable troops to perform combat tasks better by improving visibility and reducing feelings of confinement. The new coaxial machine gun mounting pin provides a reliable alternative to the current model. The silent generator concept will enable BFVs to maintain silent watch for extended periods and BFV personnel to operate critical systems without having to resort to battery or engine power.

INCREASING BRADLEY FIGHTING VEHICLE EFFECTIVENESS: IMPROVED TRAINING APPROACHES AND EQUIPMENT

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

INCREASING BRADLEY FIGHTING VEHICLE EFFECTIVENESS:
IMPROVED TRAINING APPROACHES AND EQUIPMENT

This research report provides an overview of the activities of the Bradley Fighting Vehicle (BFV) research team from 1985-1987. Each of the research projects described here was performed with the support of the Army Research Institute Field Unit located at Fort Benning, Georgia. The purpose of the research was to enhance the combat effectiveness of the BFV through improvement of existing and development of new training methods and materials, and modification of equipment and operational procedures. Background to this BFV research can be found in Rollier, Salter, Perkins, et al. (1988) and Rollier, Salter, Graber, et al. (1988).

The research concentrated on aspects of BFV usage and design that previous analysis had identified as yielding the most immediate advantage in terms of unit proficiency. Specifically, the researchers selected nine issues for development and evaluation work, while placing particular emphasis on the effects of camouflage on thermal operations. Three of these issues (thermal experimentation and training material evaluation, integrated sight unit modifications, and synthetic thermal materials) have been consolidated into a single chapter for the purposes of this report. The remaining issues (range card and optical range finder, driver alert system, transparent cargo hatch, on-board ammunition stowage, 7.62-mm mounting pin, and auxiliary generator) are treated separately in the report. In addition, as is noted, a number of the research projects will also be reported in more detail in separate, stand-alone documents.

For each identified problem, the researchers evaluated both training and hardware solutions and selected the most appropriate solutions for investigation. For example, in the area of thermal research, the BFV team developed procedures and techniques, produced training documents, and modified hardware. For all projects, ergonomic implications of design changes or modifications were closely evaluated.

The research team is confident that implementation of the recommendations in this report will materially and favorably impact the effectiveness with which a BFV can engage the enemy and will enhance its ability to persevere on the modern battlefield.

TECHNIQUES, GUIDELINES, AND PROCEDURES FOR IMPROVING THE PERFORMANCE OF GUNNERS USING THE THERMAL MODE OF THE INTEGRATED SIGHT UNIT

INTRODUCTION

This section describes thermal research conducted between September 1985 and September 1987. A detailed account is given in Champion, Rollier, Frederick, Roberson, and Knapp (1988). In addition, other pertinent documents are cited in the text where appropriate. The research was intended to identify techniques and create guidelines and procedures that would enable Bradley Fighting Vehicle (BFV) gunners to use the thermal sight more effectively. The research concentrated on the following areas:

- Investigating the effects of camouflage, cover, and concealment on the thermal appearance of targets
- Identifying thermal cues that enable gunners to classify camouflaged targets
- Testing sector scanning and exploring range estimation techniques
- Preparing procedures that enable gunners to obtain an initial thermal image rapidly
- Modifying and consolidating previous thermal training materials
- Modifying thermal sight controls to facilitate control manipulation
- Developing methods for taking color slides through the thermal sight
- Testing the efficacy of thermal reflective materials for camouflage

Background

Research into the capabilities of the thermal sight began in 1985. At that time, the BFV was newly fielded and few guidelines had been formulated. Gunners were told that the thermal controls should be adjusted like those on a television set; that is, by adjusting the focus, contrast, and brightness knobs until the image looked good. No guidance was provided on what constituted good; nor were gunners instructed to readjust the controls to compensate for changes in background, target types, viewing distances, or climatic factors. No photographs or visual aids were available to teach thermal cues or the thermal appearance of targets. On the tactical level, no techniques had been defined for conduct of sector searches and range estimation while operating in the thermal mode. In short, a clear need for a thermal training program existed, and it was to meet this need that thermal research was undertaken.

Initial experimentation began in May 1985. Its purposes were to assess the capabilities of the sight, to define optimum manipulation techniques for rapidly obtaining clear thermal images, and to explore ways of increasing the probability of detecting targets. The intent was to build a data base from which teaching guidelines could be defined. From the information obtained, a

set of guidelines for thermal sight usage was developed. These guidelines were tested in August 1985. A class on the use of the thermal sight was given to a group of soldiers who were about to join BFV units, and the performance of these troops was compared with that of a group of established BFV gunners. The results showed that those who had received the class did as well as, and in some respects better than, the experienced gunners (Rollier, Salter, Graber, et al., 1988). These guidelines were documented in three unpublished booklets (BIFV Scanning Techniques, 1986; BIFV Thermal Operations, 1986; BIFV Range Card, 1986) and were distributed to obtain feedback on their utility as instructional documents.

Concurrently, we began initial work on developing techniques for through-the-sight color photography. Our goal was to create visual aids for instructional purposes that would reproduce the thermal image seen by the gunner.

CAMOUFLAGE, COVER, AND CONCEALMENT

Research and experimentation up to this point had dealt entirely with targets in the open. The next phase examined the impact of camouflage, cover, and concealment on the effectiveness of the thermal sight, on the way it should be used, and explored the training implications. The research was conducted in two phases. The first phase was exploratory and was conducted to collect basic data on the effects of camouflage, cover, and concealment. The second phase included a more formal experiment in which subjects were required to detect camouflaged targets. Simultaneously, research continued into through-the-sight photography, ways of improving the thermal sight controls, and methods of classifying the quality of sight images. These are reported separately.

Exploratory Phase

Objective

The objective was to build a data base about the effects of camouflage, cover, and concealment on the appearance of targets seen through the thermal sight, and on the implications of such effects for operator performance.

Method

Subjects. Six subject matter experts (SMEs) who were experienced in the use of the thermal sight were used as subjects. The judgments and observations of these SMEs constituted the data that were collected. Three of the SMEs were research staff with military backgrounds and three were military personnel serving on BFVs.

Materials. Four targets and six observation vehicles were used. The observation vehicles were all BFVs; the targets were an M1 tank, an M2 BFV, an M113 personnel carrier, and a 2.5-ton truck.

Procedure. The experiment was conducted over five nights during July 1986 at Caramouche Range, Fort Benning, Georgia. Temperatures varied between 82 and 78 degrees (F); a light rain fell during the first two hours of observation on the second and third evenings.

Each target was observed while positioned at four different target location points, which were at different ranges (1180, 2120, 3340, and 3850 meters). Each location allowed sufficient room for targets to maneuver and was suitable for using different forms of camouflage, cover, and concealment. Four types of camouflage were employed: live vegetation (target in tree line or behind standing vegetation), cut vegetation, camouflage nets, and a special thermal reflective material. In addition, by using natural folds in the ground, targets were observed in both partial defilade and complete defilade positions.

For each new arrangement of targets, each observer recorded his ability to detect, classify, and identify the targets. The definitions of these terms are as follows: detection is the discovery of a thermal source or temperature disparity in the field of view that warrants further investigation; classification is the gross differentiation of targets according to class (e.g., tank, truck, wheeled vs. tracked, personnel); and identification is the determination within a class of the identity of a target (e.g., Abrams tank, M60 tank).

In this experiment, the observers knew what and where the targets were. The focus was not on whether the observers could detect the targets, but on ascertaining characteristics of the targets that would enable others to detect, classify, and identify them. The observers recorded what they could see using both white and black hot polarity, in both low and high magnification. A photographic record was kept of the thermal appearance of each target. This proved a valuable aid in subsequent discussions of the effects of camouflage.

Findings

Detectability of thermal signatures under camouflage. Based on the sample of observations, we reached the following about the effects of the different forms of camouflage. Both live and cut vegetation were effective in reducing the thermal detectability of targets. The effectiveness was proportional to the depth of the target within the tree line and/or the thickness of the vegetation placed between the target and the thermal sight. The amount of vegetation required to hide the thermal image of a target was greater than the amount required to prevent visual detection using the daylight sight. The effectiveness of cut vegetation was not noticeably degraded by decay. On the other hand, camouflage nets did little to break up the thermal outline of targets. A net alone did not prevent detection or impede classification at the 2120-meter target location point. Placing a target in a total defilade position was found to block the thermal signature of a target completely,

leaving no residual halo or radiance above or about it. Partial or hull defilade eliminated two principal heat sources: the engine and the wheels or tracks. By concealing these, cues that can help an enemy classify a detection are denied him. The artificial thermal camouflage material showed promise for use in the field. The heat-shielding properties of such materials are described in Rollier, Champion, and Knapp (1987).

Thermal detectability of target vehicles. The M1 tank, because of its turbine engine, was found to have a strong thermal signature. The exhaust emissions were so hot that even with the vehicle in complete defilade, the heat bloom on nearby trees and foliage was easily detected. Although the M1 provided a large, hot, and therefore, detectable image, its low irregular shape made it difficult to classify. The M2 BFV, when viewed through the thermal sight, was found to have no particular characteristic that made it easily identifiable. However, its predecessor, the M113, had characteristics that made it readily identifiable. These were its distinctive box-like shape, sharp change in angle at the front, and the trim vane. The trim vane, in particular, showed up because it is made of wood and therefore tends to be of a different temperature from that of the hull. The M113 was identifiable at ranges out to 2000 meters. The 2.5-ton truck rivaled the M1 tank in the intensity of its heat emissions. The engine compartment and the vertical exhaust provided a very hot and distinctive target.

General findings. The probability of detecting a target was markedly increased when the vehicle was moving. Even when heat emissions were low or well shielded, the movement itself attracted attention. Revving the engine of a stationary vehicle also made its detection easier, as did positioning the vehicle so that the exhaust side was toward the observers. The SMEs found that classification of a detection was made easier when the polarity was changed frequently. Black hot brought out the shape or silhouette of a target more clearly; switching to white hot enabled the placing of hot areas such as engine or exhaust within this hull shape.

Discussion

When a vehicle is in a forward position, it is difficult using camouflage or concealment to reduce the overall thermal difference between a target and its background and to maintain that low differential at a point where detection is unlikely. Indeed, changes in the weather, the need to run engines to charge batteries, and essential movement of personnel make it almost impossible. Freedom from thermal detection can be certain only where vehicles are placed in cover out of direct line of sight of the enemy. However, detection implies only that a heat source or thermal anomaly is noticed by a gunner and is deemed worthy of further examination. All detections are not of military interest. Wildlife, exposed areas of rock that have been heated by the sun, and other natural features can appear as relatively intense heat sources. Therefore, where the thermal signature of a vehicle cannot be totally screened, camouflage and concealment should be used to diminish the amount of heat radiated from the vehicle and to disrupt its thermal appearance so that it is difficult to classify. This is advantageous because, if an enemy cannot determine the

nature of a heat source, he cannot be certain it is a military target. Therefore, he may be unwilling to reveal his own position by firing.

Experimental Phase

Objectives

The objective was to test the efficacy of the thermal training materials being developed by the research team. These training materials had been modified in light of what had been learned about the detection and classification of camouflaged targets in the exploratory work and were supplemented by color slides of thermal images. Testing had two aspects: first, to determine whether the sight control manipulation, scanning, target classification, and range estimation techniques that had been developed were more effective than techniques currently in use; second, to see whether classroom teaching was an effective method of communicating these techniques, especially when the target audience was experienced gunners who had preconceived ideas of the best way to use the thermal sight. In addition, the experiment was used to test the thermal camouflage material, to develop through-the-sight color photography further, and to explore two methodologies for classifying the quality of thermal sights.

We generated two sets of experimental hypotheses. The first set was concerned with the efficacy of classroom instruction as a method of modifying the techniques used by trained gunners. We predicted that when the techniques used by the control group (who relied on previous training) and the treatment group (who were familiar with the new training material) were compared, more subjects in the treatment group would scan with polarity set to white hot, scan systematically in the horizontal plane, produce a better quality range card, make greater use of the range card in the turret, and achieve an initial focus quickly. The second set of hypotheses was concerned with the efficacy of the recommended techniques themselves. We recognized that not all the subjects in the treatment group would follow the recommended techniques, and that some in the control group might coincidentally happen to use them; therefore a simple comparison of the performance of the control group with that of the treatment group was not seen to be an appropriate method of assessing the efficacy of technique. This was borne in mind when the hypotheses were formulated. First, those who scanned with polarity set to white hot and who scanned systematically in the horizontal plane would detect more targets and take less time to complete scanning than those who used other techniques; second, those who made better range cards and who used range cards more frequently in the turret to help estimate range would estimate range more accurately than those who used other methods.

Method

Subjects. Thirty-five subjects were available for the experiment. The subjects were all assigned to a BFV squad or platoon and all were trained gunners. None of the subjects had taken part in previous thermal experiments.

Materials. Ten target vehicles were used: a utility vehicle (HMMWV), two trucks (2.5-ton cargo truck and 5-ton fuel truck), two tanks (M60 and M1), one M578 recovery vehicle, and four members of the M113 family of vehicles (two M113 armored personnel carriers, an M577 command post vehicle, and an M901 anti-tank missile vehicle). Subjects made their observations of the targets through the thermal sights of six M2 BFVs. Two further BFVs were used. One served as a photography vehicle; the other was used in an embedded experiment that tested the use of artificial thermal camouflage material.

Procedure. The 35 subjects were divided into two groups. Seventeen of them, hereafter called the treatment group, were given a class on using the thermal sight prior to the experiment; the other 18 relied on their previous training. The ten partly camouflaged targets were placed at varying ranges and positions in a test area. The gunners were required to detect, classify, and estimate the range of the targets at night using the thermal sight. The targets were then moved to different locations within the test area, and the process was repeated so that each gunner had a possibility of detecting a total of 20 targets. The techniques used, detection rates achieved, ability to classify targets, and ability to estimate range were recorded.

The experiment was conducted over six days. Two days were allocated for setting up the experiment and four days for collecting data. The two set-up days were used to determine the precise positions that targets would occupy on the experimental days and to establish and practice procedures. Because each of the 10 targets was to be used twice, two sets of 10 target locations had to be determined. These two sets of target locations are called scenarios A and B. Subjects were tested using scenario A during the first two days and scenario B during the second two days. The weather remained clear with temperatures in the 60s and 70s degrees (F). No precipitation occurred during the period.

On the morning of the day on which the treatment group made observations in scenario A, they were given a three-hour class on the use of the thermal sight. The class dealt with four topics: sight control manipulation, scanning techniques, classification of detections, and range estimation. Sight control manipulation covered procedures for obtaining a clear thermal image. On scanning, subjects were advised to scan with polarity set to white hot and to search the test area by using a series of overlapping sweeps in the horizontal plane, with each sweep centered at an increased distance down range. Color slides showing targets as they appear through the thermal sight were used to demonstrate how a detection appears and to show the subjects what cues to look for when classifying a detection. The difficulties of using the stadia sight to range onto camouflaged targets was explained, and subjects were advised to use a range card. The method of making range cards and how they should be used to estimate ranges to thermal targets were reviewed.

The test area was to the north and northwest of Bush Hill, Fort Benning, Georgia. This is a heavily wooded landscape containing three open areas suitable for target placement. The closest was in the eastern part at between 600 and 800 meters from the observation vehicles, the second was to the west at about 2000 meters, and the third was almost in line with the second at between 2900 and 3200 meters. Targets were positioned to give the maximum separation the terrain would allow. The closest targets were at 630 meters and the most distant was at 3150 meters. The targets were camouflaged to differing degrees using both live and cut vegetation and partial defilade positions. Camouflage was so arranged that all targets remained detectable, although not easily detectable, to the observer.

Subjects made their observations from six M2 BFVs. These were placed in a line below the crest of Bush Hill. From this position, observers in each vehicle had approximately equal views of the test area. An SME on the use of the thermal sight occupied the commander's position in each of the six BFVs while subjects were being tested. The SMEs monitored what the subjects saw by looking through the commander's extension to the sight, recorded the subjects' observations, and timed particular operations. Four of the SMEs were research staff, and two were military personnel.

Prior to each evening's experimentation, the area was searched for unplanned heat sources such as exposed rocks that had become heated by the sun. It had been hoped that such heat sources would exist because they would test the ability of subjects to distinguish between real and false targets; ways to do this had been taught in the thermal class. Surprisingly, in view of previous experience, no unplanned targets were observed on any of the nights.

Prior to each subject entering the turret, the SMEs deliberately mis-set the main thermal controls. The focus, contrast, and brightness knobs were rotated to their right stops. This gave a common start position so that the time it took the subjects to obtain a usable thermal image could be measured.

The test schedule and sequence of events experienced by the subjects were as follows:

November 2, 1986: The range was set up for scenario A. Procedures were checked and the experimental assistants were trained in data collection techniques.

November 3, 1986: The range was set up for scenario B. Procedures were checked, and the training of the experimental assistants was continued.

November 4, 1986: The subjects in the control group arrived at 1 p.m. and were briefed on the events in which they would participate. In the afternoon, each subject was taken individually to the BFV in which he would be tested, and given the equipment necessary to make a range card. Sights were turned on and cooled so that the subjects could make a visual and thermal examination of the test area. Once the range cards had been made, the subjects were moved out of the area and the targets were positioned for scenario A. Subjects returned in groups of six at hourly intervals. The first six arrived at 8 p.m. They were told that their first task would be to obtain a clear thermal image and were

warned that the controls had been mis-set. It was further explained that once the sight was set up ready for use, they should scan the area for targets. When a possible target was detected, they should stop scanning and announce the fact by saying target. They should then try to classify the target and give an estimate of range before moving on to the next target. Subjects were told that they had one hour to scan the area, but if they believed they had detected all the targets before the hour had elapsed, they could announce the fact and stop. The subjects did not know how many targets existed or the types of target vehicles. Each subject was handed his range card, entered the turret, obtained an initial thermal image, and began his search. When the first six subjects had completed the test, they were taken to a separate holding area so that they had no contact with the next six subjects. When all 18 subjects had been tested, they were returned to their garrison.

November 5, 1986: The treatment group was tested. With the exception of the three hours of classroom instruction on using the thermal sight that were given in the morning, the events for the treatment group were the same as for the control group.

November 6, 1986: The control group returned at 8 p.m. for scenario B. Procedures were identical to those for scenario A, except that there was no requirement to make a new range card.

November 7, 1986: The treatment group returned at 8 p.m. for scenario B. Procedures were identical to those for the control group in scenario B.

Results

Difficulties arose in operationalizing the experimental design. First, the test area was found to be too narrow, and with insufficient open space to ensure that all detections were independent. The SMEs confirmed that on occasions subjects had up to three targets in view concurrently, although analysis showed that the subjects did not always realize this. Second, while maximum separation between targets was obtained in scenario A, to obtain the same degree of separation in scenario B, some targets had to be located close to scenario A positions. This may have facilitated target detection in scenario B. Third, there is evidence in the data that subjects discussed and compared their performances during the 48 hours between scenarios. As a result, several subjects in the control group showed marked changes in scanning technique in scenario B. Fourth, the data for two subjects were discarded for scenario B: one because he had been awake for 40 hours at the start of experimentation; the other, because it was found that he had been put on security detail, and therefore had learned the number and types of targets to be used in scenario B. For these reasons, the data collected in scenario B are judged to be unreliable. Therefore, where scenario B data are reported, they should be treated with caution. Where results differ between scenarios, those from scenario A will be given greater weight. The results are presented in four sections: obtaining an initial thermal image, scanning, range estimation, and classification of detections.

Initial thermal image. When the subjects entered the turret for the experiment, the thermal sights had already been switched on and allowed to cool and the controls deliberately mis-set. Subjects were warned of this and told that their first task was to obtain the best thermal image they could. It was predicted that the sequence of actions taught in the thermal class would let the treatment group perform this process more quickly. However, it must be acknowledged that the use of color slides in the class may have caused some subjects, despite their experience, to form a new and better impression of the clarity of thermal image that could be obtained. Any such new realization may have resulted in subjects being more thorough, and hence taking longer.

Analysis showed that the treatment group were on average faster than the control group in obtaining an initial image, but not significantly so. It was not the average times, but the variability in the times, that was the surprising aspect of the findings. The means and ranges of the times taken to obtain an initial focus are given in Table 1. As the table shows, subjects in the control group took between 30 seconds and 10 minutes to obtain an initial focus. In the treatment group, the slowest person in scenario A took 6 minutes 24 seconds and the slowest in scenario B took 3 minutes 45 seconds. In other words, the treatment group were more consistent in the times they took to achieve an initial focus than were the control group. These differences in consistency were tested using a test for homogeneity of independent variances. In both scenarios, the differences were significant (Scenario A; $F(17, 16) = 5.926$, $p<.01$. Scenario B: $F(16, 15) = 5.773$, $p<.01$).

Table 1

Means and Ranges Found for the Times Taken to Obtain an Initial Focus for Each Group in Each Scenario (in seconds).

	SCENARIO A		SCENARIO B	
	Control Gp.	Treatment Gp.	Control Gp.	Treatment Gp.
	N=18	N=17	N=17	N=16
Mean Time to Initial Focus	201	160	156	109
Range	570 (30 to 600)	317 (67 to 384)	540 (60 to 600)	165 (60 to 225)

Scanning techniques. The class given to the treatment group recommended scanning with polarity set to white hot and scanning in a systematic pattern in which the sector is searched by a series of overlapping sweeps in the horizontal plane. The techniques used by the subjects were recorded and rated according to how closely they approached the recommended techniques. For both polarity usage and scanning pattern adopted, rating was on a three-point scale,

where 3 points indicates the recommended technique was used, 2 points indicates it was used some of the time, and 1 point indicates it was not used. These ratings facilitated analysis of the data. For polarity usage, the definitions of ratings were as follows: a rating of 3 indicated that the subject scanned in white hot (WH) only; a rating of 2, that the subject scanned in both black hot and white hot (WH/BH); and a rating of 1, that he scanned in black hot (BH) only. Similarly, search patterns were divided into three categories: a rating of 3 indicated systematic scanning in the horizontal plane only (H-S); a rating of 2, that the subject used some other systematic scanning technique that could include limited scanning in the horizontal plane (O-S); and a rating of 1 indicated erratic scanning (E-S).

The number of gunners in each group using the different techniques are shown in Table 2. In scenario A, 9 of the 18 subjects in the control group scanned with polarity set to white hot and 5 with it set to black hot. However, in scenario B, only 1 scanned in black hot and 16 of the 17 scanned in white hot at least some of the time. As noted, this change is believed to result from the gunners exchanging information between scenarios. For this reason, the techniques used by the control group in scenario A better reflect the range of techniques that may be found among gunners in general.

Table 2

Number of Gunners in Each Group Using the Specified Scanning Techniques

	Scenario A		Scenario B	
	Control n=18	Treatment n=17	Control n=17	Treatment n=16
Polarity				
WH	9	15	10	13
WH/BH	4	2	6	3
BH	5	0	1	0
Scan Pattern				
H-S	8	11	8	10
O-S	2	4	3	3
E-S	8	2	6	3

As was expected, not all the gunners who attended the class followed the recommendations given. In scenario A, 2 of the 17 subjects scanned with polarity set to black hot for part of the time, and 6 scanned using a non-recommended pattern. Also, some subjects in the control group already used the same techniques as were taught in the class. In fact, 6 subjects in the control group scanned as had been recommended in the class. The effectiveness of the class to teach and reinforce particular scanning techniques was tested by taking t-tests between the ratings of polarity usage and scanning technique found for the control and treatment groups. Because the ratings are on

three-point scales, where 3 is using the recommended techniques all the time and 1 is not using them at all, the closer the mean rating for a group approaches a value of 3, the greater the number of persons in that group using the recommended techniques.

The means of the ratings of the techniques found for each group in scenario A are given in Table 3, with the results of the t-tests taken between the groups. As may be seen, the mean ratings found for the treatment group were significantly higher than those found for the control group for both polarity usage and scanning pattern. It is therefore concluded that some modification of established scanning techniques did occur in the treatment group, which indicates that the class was effective.

Table 3

Means of the Ratings for Polarity Usage and Scanning Techniques Found for the Control and Treatment Groups in Scenario A

	Means of Ratings				
	Control Gp. n=18	Treatment Gp. n=17	t-value	df	p
Polarity usage	2.22	2.88	2.907	33	$< .005$
Scan Pattern	2.0	2.53	1.827	33	$< .05$

We hypothesized that the techniques taught in the class would improve performance in sector scanning. In scenario A, 6 subjects in the control group and 9 subjects in the treatment group used these techniques. To test the effectiveness of the techniques themselves, the performance of these 15 subjects was compared with that of the 20 subjects who deviated from them. The two performance measures used were the number of detections made and the overall time spent by each subject scanning for targets. Scanning time was recorded by the SMEs in the turrets and was defined as the total time spent sweeping the area for targets until the subject said he was content that no more targets existed. It does not include time spent consulting the range card or time spent trying to classify a detection. The average number of targets detected and average time spent scanning by subjects in each group are shown in Table 4, along with the results of t-tests taken between the groups.

In scenario A, those who used the recommended techniques detected on average 9.53 of the 10 targets; those who did not detected 8.25. The difference between the means is statistically significant. In scenario B, 13 subjects used the recommended techniques and, on average, detected 9.38 of the 10 targets; those who used other techniques detected on average 8.4 of the targets. Again the difference between the means is statistically significant.

In both scenarios, scanning time was significantly less for the group using the recommended techniques. In scenario A, those who used other techniques took, on average, 587 seconds to complete their scanning compared with 321 seconds for those who used the recommended techniques. This is equivalent to a 45-percent reduction in time. In scenario B, the figures are 645 seconds for the group who used other techniques and 291 seconds for those who used the recommended techniques, a reduction in scanning time of better than 50 percent.

Table 4

Mean Number of Targets Detected and Mean Scanning Times Found for Each Group in Each Scenario, and the Results of t-tests Between the Groups.

SCENARIO A	Recommended Techniques n=15	Other Techniques n=20	t-value	df	p
Mean Number of Detections Made (Max = 10)	9.53	8.25	2.308	33	$<.025$
Mean Scanning Time (Seconds)	321.1	587.2	1.785	33	$<.05$
SCENARIO B	**Recommended Techniques n=13**	**Other Techniques n=20**	**t-value**	**df**	**p**
Mean Number of Detections Made (Max = 10)	9.38	8.40	2.815	31	$<.005$
Mean Scanning Time (Seconds)	291.3	644.8	2.001	31	$<.05$

Further analysis using multiple linear regression showed that polarity usage and scanning pattern contributed significantly to the number of detections made, but that scanning time was only determined to a significant extent by choice of polarity. To summarize, because the use of the recommended scanning pattern ensured complete coverage of the sector, its use significantly increased detection rates; and because the use of white hot polarity made targets easier to detect, the number of detections made increased and the search time was reduced.

Range estimation. The exploratory research had shown that range estimation to camouflaged targets detected using the thermal sight was difficult. If the target is in the open and its shape can be distinguished,

then the stadia sights can be used; however, when the target is partly screened by vegetation or is in partial defilade, this becomes difficult. Therefore, we hypothesized that more reliable estimates would be made if gunners were encouraged to make greater use of range cards. To this end, the thermal class taught the importance of making an accurate range card and of using it to determine the range of targets detected through the thermal sight.

Analyses addressed two questions. First, was the class effective? That is did those who attended produce better range cards, and did they make greater use of them in the turret? Second, was the technique effective? That is, did those who produced good range cards and who made use of them in the turret, estimate range more accurately?

Although it could be shown that the subjects in the treatment group did produce, on average, better range cards, and did estimate range more accurately (significantly so, in scenario A) than did the control group, analysis showed that neither group made much use of the range card in the turret. Of the 17 subjects in the treatment group, 11 either did not use the card or used it minimally (less than one minute in total). When the two groups were combined (35 subjects), it was found that only 6 subjects had made a range card of reasonable quality and used it for more than one minute in the turret. Therefore, the effectiveness of this range estimation procedure could not be evaluated, and we must conclude that the part of the class dealing with range estimation was ineffective. We hypothesized that the reason the treatment group produced better range cards and estimated range more accurately was that they were forewarned of the need, and better motivated (by the class) to try.

The experiment did yield general information on the accuracy with which gunners can estimate the range of partly camouflaged targets at night using the thermal sight. Of the 20 targets used in the two scenarios, 5 were located close to the observers at a range of 630 meters. The 35 subjects made a total of 155 estimates of range for these five targets. Three of these estimates put the range at less than 500 meters, 16 put the range at between 500 and 750 meters, and the remaining 136 estimates placed the targets at greater distances. The average of the 155 estimates was 1188 meters. These figures reveal a marked tendency to overestimate the range of near targets. Four targets were located at between 3050 and 3150 meters. A total of 98 estimates of range were recorded for these four targets. Of these estimates, 29 (30 percent) put the range at between 3000 and 3200 meters. No gunner estimated the range to be greater than 3200 meters. The average of the estimates made was 2312 meters. To summarize, the gunners tended to overestimate the distance to near targets and underestimate the range to far targets (of the 583 estimates recorded, 339 (58 percent) were between 1000 and 2000 meters, even though this area contained only 30 percent of the targets).

<u>Classification of targets</u>. In the context of the experiment, classification was defined as determining whether the targets detected were tracked or wheeled vehicles. Time was given in the thermal class to classification, and the gunners who attended were instructed to switch polarities when classifying targets to bring out the shape of the target, to look for engine location, and to count road wheels if these could be seen. These points were emphasized by the use of color slides of sample target

vehicles. We therefore predicted that those who attended the lecture would prove to be better at classifying targets than those who did not.

Analysis showed that there were no significant differences in correct classification rates between the two groups. The gunners in the control group on average correctly classified 56 percent of their detections in scenario A and 50 percent in scenario B. The gunners in the treatment group on average correctly classified 53 percent of their detections in scenario A and 56 percent in scenario B.

Discussion

Thermal training class. The thermal training class was shown to be an effective instrument for modifying and/or reinforcing the current practices of experienced gunners in the following two areas: sight control manipulation and scanning techniques. It was not effective in persuading gunners to use the range card to estimate range. The probable reason for this has been suggested to be resistance by the gunners to the idea. In the first two areas (sight control manipulation and scanning), the instructor was able to demonstrate the value of the points he was making by showing color slides of thermal images. The clarity of image that could be obtained and the advantages of using white hot polarity to scan were therefore made obvious to the audience. For the range estimation technique, no such visual proofs were available. The instructor was therefore constrained to demonstrate the advantages theoretically; and for the experienced people who constituted the audience, this was clearly not enough.

Effectiveness of the techniques. Clear evidence was found that the sight control manipulation techniques taught in the thermal class were beneficial. The increase in consistency of the time required to obtain an initial thermal image is indicative of a more precise and thorough technique. Based on the figures found in scenario B, when subjects had some practice, one would predict that by using this technique 80 percent of gunners would achieve initial focus within 2 minutes and 45 seconds. For gunners using the variety of techniques found in the control group, the equivalent time would be 4 minutes and 52 seconds. Post-experiment reports of the SMEs showed that some gunners in the control group began scanning before they had achieved a clear thermal image and only fine-tuned once they had made their first detection. This is of concern. Such a technique may cause a gunner to fail to detect a well-camouflaged target. Therefore, there is a need for a clear-cut procedure for obtaining an initial thermal image and a need for a standard defining the clarity of that image. The procedures taught in the class, together with the color slides to provide the standard, meet this need.

The effectiveness of the scanning techniques taught was also demonstrated. The use of both white hot polarity and a systematic horizontal plane scanning technique significantly increased the number of detections made and led to a significant reduction in scanning time. Scanning with polarity set to white hot is consistent with current training at Fort Benning. We were therefore surprised to find so many in the control group scanning in black hot at least part of the time. This may reflect training received at an earlier period, or

it may reflect an inconsistency in training. The recommendation that gunners scan in the horizontal plane has two obvious advantages: first, it ensures that the whole sector is thoroughly scanned; and second, for reasonably level terrain, it minimizes the need to adjust the focus during each sweep. One proviso should be added to these findings. The experimental test was conducted in a mixed woodland area. We do not know whether the techniques can be generalized to other climatic zones such as desert or arctic areas.

The effectiveness of the range estimation technique taught in the class could not be assessed because an insufficient number of subjects used it. The adequacy of the classification guidelines was also not effectively tested. Primarily, this was because there were no false targets in the field of view. In future experiments, the desirability of deliberately including both false targets and a greater variety of military targets should be considered. This is because classification is a more complex process than was tested in this experiment. Gunners must be able to distinguish troop movements and fortified positions from vehicles, and to distinguish all of these from non-military heat sources such as animals and agricultural and civilian equipment.

Implications for thermal training. The performance of the control group demonstrated and confirmed the need for thermal training guidelines in the following three areas: obtaining an initial thermal image, scanning, and range estimation. The performance of the treatment group demonstrated the effectiveness of the training guidelines developed in the first two of these areas. The third remains untested. In the light of the experimental findings, the previously established guidelines were reworked wherever possible into formal procedures and assembled into a handbook that could be used for on-the-job training. In addition, a slide presentation was prepared that would teach BFV crew about the capabilities of the thermal sight, familiarize them with the thermal appearance of detections, and would provide examples of thermal cues that facilitate classification. The handbook and slide presentation together constitute a basic thermal training package (Rollier, Champion, Roberson, & Graber, 1988). This package is described separately in the following section.

OTHER RESEARCH AND PRODUCTS

Thermal Training Package

The handbook contains the following: an introduction describing in simple terms how the thermal sight works; a brief review of the thermal controls, stating their purpose and with an accompanying diagram showing their appearance and location; a step-by-step procedure for obtaining an initial thermal image; a procedure that will let a gunner pre-mark the controls so that an initial thermal image can be obtained rapidly and easily; a procedure for scanning a sector; a procedure and guidelines that tell a gunner what to do when he detects a heat source and guides him in classifying it; and guidelines on estimating range using the thermal sight.

The slide presentation comprises 28 color slides with accompanying script. It is arranged so that subjects see a target first as it appears through the

day sight in daylight and then as it appears in thermal. The slides cover the appearance of the thermal landscape, detections in low magnification, the effect of switching to high magnification, and polarity use. They point out thermal cues that aid target classification and show targets at ranges from 630 meters to 3150 meters. Some of the targets are partly camouflaged and some are in the open. The slides are of good quality and will serve as a standard to teach the clarity of image that can be achieved with a well-adjusted sight.

Through-the-Sight Photography

The need for slides of thermal images of targets that could be used for training purposes was identified early in the thermal research program. Development of the necessary techniques has been an on-going process. A selection of slides from the last major field experiment comprise the slide presentation described above. The technique for making these thermal images is described in detail in Champion, Rollier, Frederick, et al. (1988).

Thermal Sight Classification Techniques

Some exploratory work was done on developing a system for classifying the quality of thermal image given by the thermal sights. The purpose of this work was to provide a predictor of the need for sight maintenance, as well as to provide a method of comparing and standardizing across sights for experimental purposes. Two methodologies were explored. The first relied on subjective assessment according to established criteria. The second was an objective method whereby a panel with heated geometric symbols was viewed through the sight. We theorized that poor definition of, or distortions in, the geometric shapes would indicate the nature of problems and would permit classification. Validation of the system would be accomplished by correlating the data obtained from the two methods.

An initial set of criteria for the subjective measures was written and received limited testing on seven BFVs. This is more fully described in Champion, Rollier, Frederick, et al. (1988). For the objective measure, a prototype panel was built, and again some initial testing was conducted. This testing was essentially confined to determining the temperature to which the symbols should be heated, so that their appearance corresponded in brightness to real targets down range and to experimenting with symbol shapes. While the results showed some promise, it also became clear that development would be a slow process, and time constraints forbade further work.

Modifying Selected ISU Controls

During experimentation, gunners often had difficulty in obtaining and maintaining a usable thermal image. At least in part, these difficulties result from poor ergonomic design of the sight controls. For example, the focus knob will rotate about 12 full 360 degree rotations between stops; focus occurs during one part of one of those rotations, usually the fifth. As a result, when rotating this control, gunners can easily miss the focus area and

turn on to the far stop before they realize their error. Similarly, the contrast and brightness knobs rotate very freely on their axes and are easy for gunners to displace inadvertently.

There are two possible solutions. The first is to provide a training/procedural solution. This solution was adopted to help gunners obtain an initial thermal image, as has been noted previously in this report. The second solution is to modify the controls themselves. Clearly, because many BFVs have already been fielded, this option can be considered only if the modifications can be quickly and easily made, at minimal cost, and using minimally skilled personnel. Such a modification has been developed for the contrast and brightness knobs by the insertion of a vinyl grommet between the panel and the knob. The grommet provides a friction brake on the free rotation of the knobs so that they are stiffer to turn and therefore less prone to accidental movement. At the same time, a guard was placed on the night sight power on/off switch. This switch is normally unguarded and is subject to accidental switching when gunners make vertical hand movements to reach for other controls. These modifications were tested and judged to work,well. They are reported in detail in Champion, Rollier, Knapp, and Lewis (1988).

Use of Special Camouflage Materials

Concurrent with the investigation into the effects of camouflage on the thermal detection of targets, the question arose of how friendly vehicles and positions might be hidden from enemy thermal sensors. One suggestion that was explored in detail was the use of the sort of material from which thermal blankets are made. This material contains a metal foil that reflects heat, is lightweight, and occupies little space when packed. Experimentation with such material has been continuous and has addressed not merely the effectiveness of the material as a shield to prevent thermal radiations reaching enemy sensors, but also issues of durability and flammability. Insofar as the current camouflage nets provide very little protection from thermal detection, the concept is worthy of exploration. Much of the initial groundwork has now been done, but further research is required before definitive recommendations can be made. This research is reported in detail in Rollier, Champion, and Knapp (1987).

SUMMARY

Thermal research has been very successful. The exploratory work into the effects of camouflage, cover, and concealment has yielded new and reassuring information about the capabilities of the thermal sight. That using it some gunners could detect and classify partly camouflaged targets at ranges in excess of 3000 meters was notable. Moreover, the finding that targets that had been camouflaged sufficiently to avoid detection through the daylight sight could still be detected with the thermal sight, emphasizes its utility for both day and night operations.

Concurrently, the research yielded guidelines for camouflaging vehicles to avoid detection, and, more important, to impede classification by hostile forces equipped with thermal sensors. The investigation into the use of synthetic thermal camouflage material showed promise and is thought to have potential for reducing the likelihood of detection by threat thermal devices.

The techniques for through-the-sight photography have been advanced to a point where color slides showing thermal targets are of high quality and can be used for teaching purposes. These slides should prove to be valuable training aids to instructors. They will enable the advantages of particular search and detection techniques to be demonstrated easily, as well as provide a method for teaching students the thermal cues that aid target classification.

The consolidation of the existing guidelines on sight control scanning techniques, manipulation, and range estimation, into a single, reproducible handbook, and the restructuring of the guidelines into step-by-step procedures, should facilitate training. The modifications to the ISU's contrast and brightness knobs were well received when tested. The modifications materially reduce the probability of inadvertent displacement of these controls. The experimental evidence demonstrates the advantages of systematic scanning with polarity set to white hot and is noteworthy.

RECOMMENDATIONS

There is a need for continued research into the use of the thermal sight. We recommend that the following areas be explored:

- The identification of the thermal characteristics of threat vehicles and the development of a simple classification and identification system for them
- The exploration of the capabilities of the thermal sight in conditions of limited visibility
- The production of a series of short thermal training films dealing with such topics as Target Detection and Classification (Hostile Forces), Thermal Camouflage, and Thermal Operations in Conditions of Limited Visibility

In addition, we recommend that further research be conducted in the following areas:

- Range estimation using the thermal sight
- Thermal sight classification techniques
- Simple modifications to the ISU's controls
- Integration of synthetic materials with camouflage nets to provide visual and thermal protection

EXPLORING PROBLEMS OF CONCERN IN RANGE ESTIMATION

We have received reports from instructors at the United States Army Infantry School (USAIS) and from tactical unit commanders that indicate that U.S. soldiers lack range estimation skills. This shortcoming is noteworthy because it decreases the combat capability of all types of infantry units by increasing the ammunition expenditure required to achieve enemy target hits and kills and increasing the chance of revealing friendly weapons positions, which can result in loss of surprise and invite accurate counterfire. It especially impacts Bradley Fighting Vehicle (BFV) units because range estimation becomes more critical as the effective range of employed weapons systems increases.

Until recently, U.S. Infantry forces were taught range estimation as a part of basic rifle marksmanship (BRM). A range estimation area was located in the vicinity of live fire ranges and soldiers were tested on their ability to estimate range using a series of colored/lettered panels positioned at specific distances from the test site. At present, a thorough knowledge of field expedient range estimation techniques remains an important adjunct to effective use of antiarmor and automatic weapons, but this vital skill receives only cursory mention during training.

To better understand the range estimation problem, we conducted investigations that reviewed range estimation techniques available for use by the soldier; analyzed the current range card used by USAIS instructors; and developed a hand-held, pocket-size optical range finder to assist soldiers in estimating range.

Range Estimation Techniques

Our review of ranges estimation indicated that available field expedient range estimation techniques may be used with reasonable accuracy when learned and practiced (FM 7-7, The Mechanized Infantry, 1985; FM 17-12, Tank Gunnery, 1977; FM 23-9, M16A1 Rifle, 1974; FM 17-95-1, Cavalry for Rangers, 1977; FM 21-75, Combat Skills, 1984; FM 23-1, Bradley Fighting Vehicle Gunnery, 1986; STP/21-1, The Soldier's Manual, 1985; Thompson, 1982). These techniques include the tracer burn out method, the appearance of objects method, ranges of sounds in the night method, the 100-meter method, and the halfway point method. Using these methods could help soldiers to achieve the objectives of conserving ammunition, successfully engaging the enemy, and producing increased target hits and kills. However, we concluded that even the skilled observer will be restricted to estimating ranges that are generally less than 2,000 meters, and that, even with practice, he will find these techniques difficult to remember and use under battlefield conditions. The limitations of these field expedient techniques convinced us that soldiers are in need of a type of optical range finding device that is discussed later in this chapter.

Range Cards

The researchers observed field training exercises and range firing and conducted experiments during which range cards and range information were not used effectively. We also observed that range cards receive little or no emphasis in either institutional instruction or tactical exercises. As a result, few individuals know how to prepare an effective range card, and its use to assist in determining distance to a target is rarely observed. Where preparation of a range card is considered to be mandatory, as it is during Army training and evaluation programs (ARTEPs) and similar rated exercises, there is no provision for rating employment of the range card as a part of the gunnery process. The researchers were informed, repeatedly, by leaders and instructors that the range card is a waste of time.

These observations suggested that soldiers are not convinced of the value of the range card. It is a complex task to prepare a good range card, particularly because different cards are used for different weapons (i.e., M-60 and .50-caliber machine gun, DRAGON and TOW anti-tank missile, and the M-60 and M-1 tank). It is our observation that this complexity leads to misunderstanding, lost motivation, and perfunctory compliance with the requirement to make and use range cards.

Using the USAIS-developed Improved TOW Vehicle (ITV) range card as our initial model, we worked to simplify and clarify the requirements involved in the range card preparation process. The range card we developed has two parts. The first provides space for the soldier to draw a sketch of the terrain that he is directed to cover by fire with his weapon or weapons system. The second provides space for the soldier to record the information (data) he will need to plan and control that fire. Together, this information permits the soldier to detect and engage targets under all visibility conditions and serves to orient replacement personnel and units who may occupy the position later.

We also developed a number of instructions for preparation of the range card, which were placed on the reverse side of the card. In addition to instructions for card preparation, the reverse side included standard map symbols to assist the gunner in sketching the terrain, and standard weapons symbols to ensure proper identification of the type of weapon for which the range card is prepared. The construction of the range card, itself, was further simplified by increasing the number of range rings from nine to ten. This reduced the mental arithmetic required to determine the distance between range rings by having the soldier divide by ten rather than by nine. Also, more space was allocated for drawing and writing to improve the range card's readability (especially at night), and the columns in the data section were arranged from left to right by priority of use. A sample blank range card, a set of detailed instructions, and a complete sample range card are enclosed in Appendix A.

Preliminary research suggested that the ability of the average soldier to produce an even marginally adequate range card is lacking (Champion, Rollier, Frederick, et al., 1988). And we would note that the usefulness of this or any other range card is almost totally dependent on the knowledge and use of field

expedient range estimation techniques or range estimating devices. However, we recommend USAIS test the range card and accompanying instructions and, where appropriate, incorporate the range card into courses of instruction.

Optical Range Finder

As noted in the previous section, range estimation is critical to proper construction and use of the range card. Without accurate range estimation the range card loses its primary purpose, which is to permit accurate engagement of targets by both direct and indirect fire with the greatest possible lethality. Further, current doctrine suggests that it will not be unusual for a BFV squad to dismount and conduct missions while receiving supporting and overwatching fires from the squad vehicle. During these missions, distances from the dismount squad to the BFV will vary from only a few meters to several hundred meters, and the ability to estimate range accurately will influence success. Undoubtedly, some units will have laser range finders and other extremely accurate devices for range estimation tasks, but most units, because of the high cost of these devices, will have to depend on traditional field expedient range estimation techniques. We have already noted that field expedient range estimation techniques have practical limitations and that the techniques are neither well understood nor effectively employed. As a possible solution to these range estimation problems, we explored the feasibility of developing an inexpensive, but accurate, optical range finding device. Optimally, it was thought, the range finder should be small enough that the squad leader and platoon leader could each attach one to their load-carrying equipment or place one in their battle dress uniform (BDU) pocket.

We contacted several vendors and selected one to build a prototype optical range finding device suitable for limited field evaluation. It was agreed that the initial prototype would be between 12 and 15 power, 1.25 to 1.50 inches wide, and between 7 and 8 inches long (pocket sized), and have a reticle scale based a two-meter tall object, with 500-meter increments from 0 to 3500 meters. The scale was selected because many targets and common objects found on the battlefield are approximately two meters high.

The first range finder was evaluated as a sub-test to another experiment conducted between 2 and 7 November 1986. Details of this research project can be found in Rollier and Frederick (1987). This evaluation used available targets, at ranges between 630 meters and 3150 meters. Civilian personnel and military officers and enlisted men acted as evaluators. The evaluators unanimously endorsed the concept of the optical range finder. They pointed out, however, that the range finder lacked sufficient magnification for targets in excess of 2000 meters, the focus control was difficult to use, the range finder needed lens covers, and it lacked stability.

Based on these comments, the vendor produced a second prototype (Figure 1) with magnification increased from 15 to 30 power and a reticle that was made more readable by increasing the distance between range lines. Another field evaluation was conducted during an experiment on 6 July 1987.

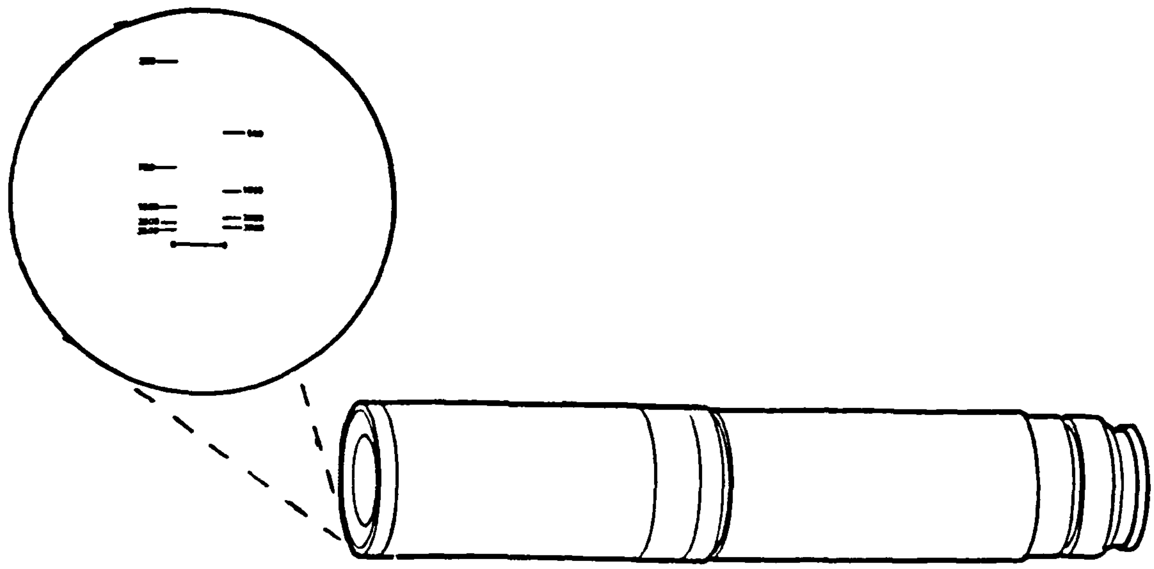


Figure 1. Second prototype range finder.

Sixteen non-commissioned officers used and evaluated the optical range finder. Based on this evaluation, the researchers concluded that the optical range finder instructions are easy to understand, that it is easy to use, and that it is about the right size. The evaluators believed soldiers could make accurate range estimates with the prototype optical range finder and they, themselves, would prefer to have the range finder as part of their personal equipment, even if they have to purchase it from commercial sources.

Using the information derived from these evaluations, we plan to refine the design of the optical range finder and to conduct further tests. The preliminary information gathered to date suggests, however, that this device offers a solution to many range estimation-related problems that currently hamper the readiness of U.S. soldiers.

A DRIVER ALERT SYSTEM FOR THE BRADLEY FIGHTING VEHICLE

In battle, the success of the Bradley Fighting Vehicle (BFV) depends on the rapid exchange of information between the commander and driver. It is this immediate communication that can quickly direct the vehicle into action or out of danger. However, a recent report of BFV performance identifies loss of communication between the commander and driver as a critical problem (Rollier, Salter, Perkins, et al., 1988). This problem is compounded during extended field exercises when excess mental workload and physical exhaustion degrade human performance. For example: A member of our research team observed such an incident in Hohenfels, Federal Republic of Germany, when a vehicle was left behind as a platoon moved out because the driver had fallen asleep and had to be physically roused (R. L. Rollier, personal communication, February 1984).

The commander has three methods of communicating with the driver. First, the intended method is for the commander to use the radio/intercom system. This is not always reliable because the radio and intercom cannot be used simultaneously. The radio/intercom can also fail as a means of communication when the driver has removed his combat vehicle crewman's (CVC) helmet or when battlefield damage, electrical malfunction, electromagnetic pulse (EMP), or interference and jamming have rendered the system inoperable. Second, if the intercom fails, the commander can relay messages through personnel in the troop compartment. Third, if the intercom fails and the dismount element is deployed, the commander must exit the turret and go to the driver's position to give the order. Clearly, this entails an undesirable delay in getting the vehicle moving.

The driver alert system (DAS) is a proposed solution to this problem. (A detailed description of the DAS system, including testing of the system and installation instructions, is provided in Champion, Roberson, and Lewis (1988).) It comprises an audible alert placed in the driver's compartment, and an activating switch located in the commander's position in the turret (Figure 2). The alert is located approximately 24 inches to the left of, and in line with, the driver's head position. The optimum location of the activating switch was determined to be below the weapons control panel so that it could be easily reached by the commander and the gunner.

When considering the precise type of alert to be used, three requirements were defined. First, the alert had to be loud enough to be clearly detectable in the driver's compartment, above the noise of the engine and ancillary systems such as air blowers; second, the pitch and tonal quality had to have attention-demanding properties that would be likely to awaken a sleeping driver; third, it could not be so loud as to either pose a threat to the hearing of the driver, or to alert the enemy if the BFV were in a stationary position with hatches open.

To enable a definition of the type and loudness of the alert, first, an octave band analysis 24 inches from the driver's head position. This level was above requirements. Testing determined the optimum level for the alert to be 96 db as measured at the subject's head position. At 96 db the alert was

concentrated in the low- to mid-frequency octave bands. We determined that the frequency of the alert should be above this level, in the 4-kilohertz (khz) octave band (approximately 2666-5332 hz). This would permit a reduced loudness for the alert to be specified, while maintaining a good signal-to-noise ratio.

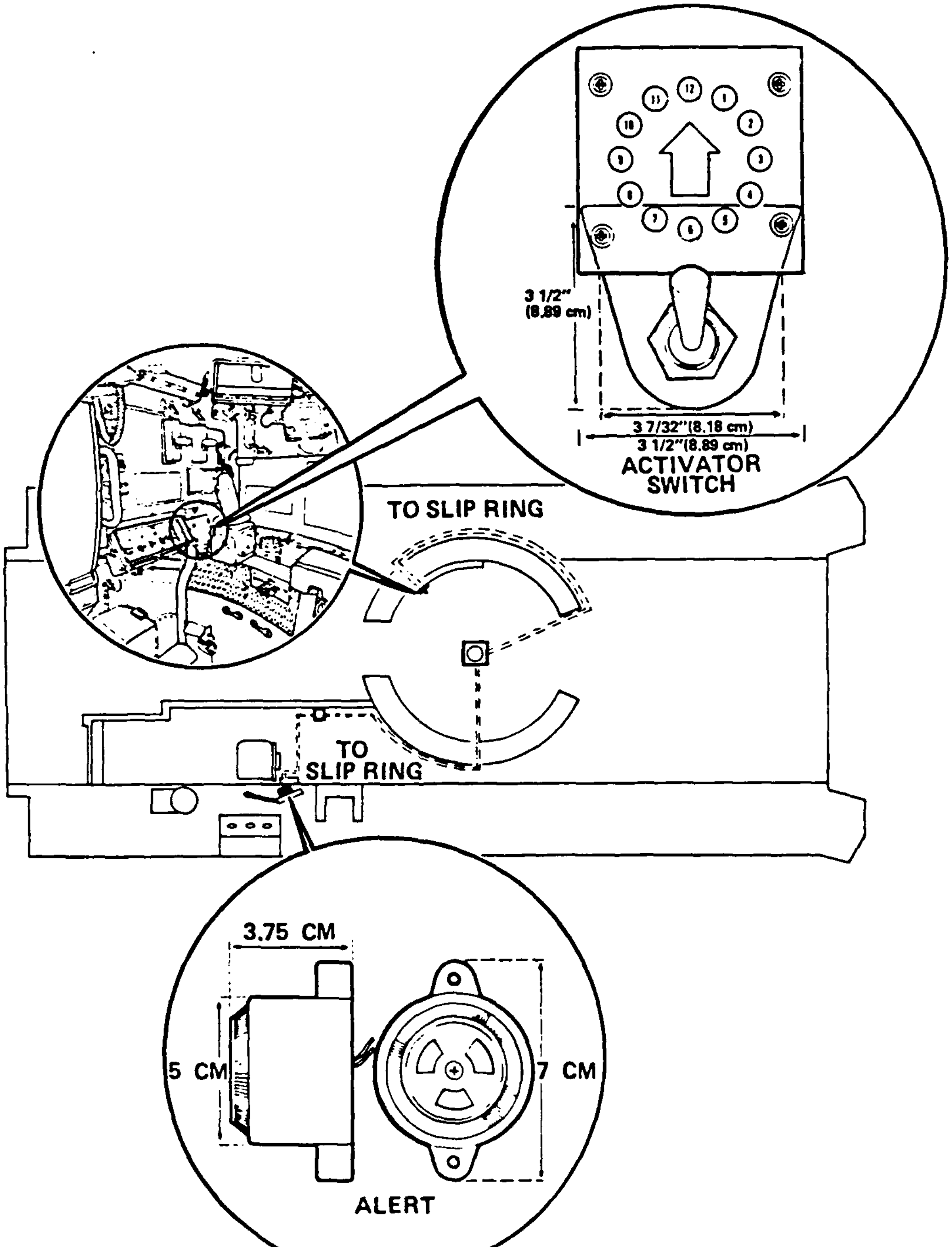


Figure 2. Configuration of the driver alert system (DAS) and location within the BFV.

We obtained several alerts from manufacturers and compared them. The alert that was selected gave an oscillating note with good attention-demanding properties. The manufacturer's frequency specification for this oscillating alert put the device at 3000 Hz (+/- 300 Hz), with the sound level capable of being varied between 90 and 100 dBA at 1 meter. The researchers subsequently installed the DAS in a BFV. Measurement showed that it also put out some energy in the 2-kHz octave band and could deliver up to 106 dBA at a distance of 24 inches from the driver's head position. This level was above requirements. Testing determined the optimum level for the alert to be 96 db as measured at the subject's head position. At 96 dB the alert was clearly audible to the driver in the noisiest of test circumstances. In the 4-kHz mid-octave band, it was 9 dB above the sound levels generated by the BFV with the engine and blowers on. When tested with the engine and blowers off, and with the hatches open, it could not be heard at 70 meters upwind or 400 meters downwind (wind strength 10-15 mph); however, the ramp horn could be heard at greater distances. Because the driver's CVC attenuates noise by 35 dB in the relevant frequencies, the recommended level for the DAS poses no threat to the driver's hearing. The DAS has received limited field testing so far, and while its ability to attract a driver's attention is established, its ability to awaken a heavily fatigued driver cannot be answered at present.

The DAS should be given a definitive test. This would require installing the DAS in several vehicles on a field exercise of sufficient duration to cause the driver to become very fatigued. Installing the DAS on vehicles bound for an exercise at the National Training Center (NTC) would be the best test. The field-training exercises at NTC are of sufficient duration and are fast-paced enough to assure BFV drivers' fatigue.

A TRANSPARENT CARGO HATCH FOR THE BRADLEY FIGHTING VEHICLE

This section briefly reports research into the development of a transparent cargo hatch for the BFV. The transparent hatch was investigated at the request of the U.S. Army Infantry School (USAIS), as a means of performing a number of specific tasks. Of special interest to the USAIS was the need to improve visibility from the troop compartment of the BFV. Improved visibility would allow the dismount element to orient to the terrain prior to deployment. It was also felt that increased visibility would reduce concerns about such on-board functions as local security and passive air defense. Research into this topic is reported in full in Rollier, Champion, and Roberson (1987).

The troop compartment of the Bradley Fighting Vehicle (BFV) limits the ability of soldiers riding in it to monitor the external environment. This has important consequences. First, because the vision block system provides only a limited field of view, soldiers deploying from the rear of the BFV have little opportunity to gain a clear idea of the surrounding terrain or to pick the points to which they will have to move. Second, the limited field of view from the seven vision blocks leaves much dead space around the vehicle, and this reduces the ability of personnel to perform local security and to operate the M231 Firing Port Weapons effectively. Third, vision is inadequate for performing passive air defense, Fire Support Team (FIST), and Forward Observer duties; therefore, these duties are currently given to the commander and gunner, who already have high workloads. Fourth, the confined space can be claustrophobic, and the lack of external visual fixation points can induce motion sickness.

We first reported problems caused by the poor vision out of the BFV's enclosed troop compartment in 1984 (Rollier, Salter, Perkins, et al.). This was followed by a more detailed investigation of the problems that included the development of the first of three prototype transparent cargo hatches. Details of this action can be found in Rollier, Salter, Graber, et al., (1988).

In brief, as part of the 1985 project, we generated a set of requirements that defined the vision parameters for the crew compartment: (a) a minimally obstructed 270-degree view of the battlefield to the sides and rear of the BFV, (b) a minimally obstructed view from the horizon to overhead, (c) a design that could be implemented with little or no hull modification, (d) an undistorted view, and (d) retention of at least the same level of protection afforded by the current vehicle design.

Also in 1985, the researchers identified technologies showing potential for improving visibility from the troop compartment. Three options were explored: reconfiguration of the present vision blocks, fiber optics relay of the ISU sight picture to the troop compartment, and a redesign of the current cargo hatch cover that would incorporate transparent armor. Team members evaluated the feasibility of each potential solution and selected the option of redesigning the cargo hatch cover as the most promising. This was because, apart from meeting the requirements, we estimated that this approach would involve the least modification to the hull.

The current cargo hatch is located over the rear crew compartment. It is armored to the same extent as the rest of the BFV, and during operations may be opened to permit the reloading of TOW missiles which are stowed in the rear compartment. Clearly, any redesign would have to provide the same degree of protection as the present forged aluminum hatch cover (i.e., Soviet 14.5-mm armor piercing (AP) at 300 meters), allow for reloading of the TOW missiles, and not interfere with the rotation of the turret.

As noted, after reviewing the problem areas and the requirements for the proposed solution, the researchers developed a prototype hatch frame. The hatch frame was made of light carbon steel and measured approximately 49 x 30 inches at the base, with a center height of 11 inches. The sides were sloped at 30 degrees from vertical and contained panels of transparent armor, as did the top of the hatch. The prototype was fitted on a BFV to determine whether it satisfied the requirements.

For the on-vehicle test, we placed a prototype on a BFV that was scheduled to participate in a tactical exercise. One staff observer rode in the rear compartment to take detailed notes. The observations showed that the use of transparent armor did meet the stated requirements. Forward Observer (FO) tasks were performed effectively. In fact, the FO stated that the hatch had permitted him to maintain orientation, for the first time, while riding in a BFV. Early detection of enemy air threats was shown to be possible. The amount of close-in dead space was reduced to within approximately three meters of the vehicle. Rain, mud, and condensation (all experienced during this test) were not found to degrade visibility seriously through the transparent armor panels. Finally, post-test questionnaires showed that troop compartment personnel preferred the new hatch to the original cargo hatch.

Users expressed some concerns that reinforced our awareness of the need for the following actions: design a seat with height adjustments to provide support and increase comfort for the individuals observing from the hatch, add interior opaque covers with Velcro fasteners to the hatch to enable light discipline at night, provide proof that the modification affords ballistic protection equal to or greater than the present aluminum hatch, and provide proof that light reflection from the cover is manageable and will not increase the chance of detection.

The investigation indicated that the transparent cargo hatch had the potential to solve troop compartment visibility problems. However, the evaluation also showed that the first two prototypes required major redesign. The one-piece hatch proved too bulky and heavy, while its attendant hardware (hinges, latches, and springs needed to raise this weight to the open position) obscured vision to the rear of the BFV. The researchers decided to pursue this line of investigation further, starting in 1986.

1986 Research

The team's renewed approach to solving the visibility problem included three major components. First, analysis of the problem. Second, ballistic testing of transparent armor samples to measure the level of protection provided. Third, development of new prototype designs. In combination, these steps allowed us to refine the transparent cargo hatch further.

The problem analysis essentially involved a review of previous work. We also used this opportunity to display the prototypes developed earlier for military personnel and subject matter experts (SMEs) and noted their comments. As a result of this process, the investigators retained the original design requirements but added two new constraints:

- The amount of effort required to open and close the hatch should be within ergonomically defined limits

- The prototype transparent cargo hatch design should further improve visibility over the designs developed during the 1985 investigation

Although samples of transparent armor had been secured during 1985, none of these samples was ballistically tested. A major objective of this investigation, then, was to subject samples to .50-caliber machine gun fire (and later 14.5-mm machine gun fire) to see if the samples could provide the required level of protection for troop compartment personnel. The researchers were chiefly interested in finding transparent armor that could withstand 14.5-mm armor piercing (AP) machine gun fire without penetration or spalling.

While conducting ballistic testing, we were also concurrently designing the framework for a new prototype hatch. As noted, the first prototypes had proven too heavy. To a lesser extent, the investigation had shown that the hatch also restricted visibility too much to be effective. The researchers planned to design a prototype that would overcome the previously identified problems. To better evaluate the design, we also planned to construct a prototype that could be subjected to a real-world evaluation.

Manufacturers of bulletproof glass were canvassed to determine the availability and estimated cost of transparent viewing surfaces that would meet the project criteria. The researchers obtained and later tested 12 transparent armor samples on three occasions using a .50-caliber machine gun. The researchers had originally intended to use a 14.5-mm machine gun during Test 3. Unfortunately, the 14.5-mm failed, and a .50-caliber machine gun had to be used.

Five of the 12 samples tested resisted penetration and/or spalling. Sample three from Test 2 consisted of 3 inches of ballistic glass installed in a prototype hatch cover. The bullet hit near the bottom, penetrated, and exited 2 inches from the bottom and 2 inches from the right edge. The bullet did not penetrate the sample; however, spalling did occur. The impact created an area of cracking approximately 7 inches high by 22 inches wide extending over approximately 90 percent of the surface of the sample. A second shot to another 3-inch-thick panel in the hatch produced similar results.

Sample four consisted of 1 9/16 inches of glass and plastic laminate with a 7/8-inch plastic backing for a total of 2 7/16 inches. The bullet hit the sample 11 inches from the bottom and in the center of the sample. The bullet penetrated and exited 9 inches form the bottom, center. No spalling occurred, but 90 percent of the sample surface was cracked.

Sample five consisted of 2 1/16 inches of glass and plastic laminate with a 1 3/8 inch plastic backing. The bullet hit the sample 7 inches from the left edge and 8 inches from the top. The bullet penetrated but was considerably turned in its course and exited 8 1/2 inches from the top and 2 3/4 inches from the left edge. No spalling occurred, but the sample was badly cracked.

Sample six from Test 2 consisted of 2 9/16 inches of glass and plastic laminate with a 15/16-inch plastic backing for a total of 3 1/2 inches. The bullet hit the sample 10 inches from right edge and 10 inches from the top. The bullet was turned in its course and exited through the top right edge of the sample at a depth of 2 3/4 inches. No penetration or spalling occurred. A second shot was fired at the damaged sample. It entered 7 1/2 inches from the bottom and 10 1/4 inches from the right edge, penetrated, and exited 10 inches from the right edge and 11 1/2 inches from the bottom. No spalling occurred.

Sample two from Test 3 consisted of 3 inches of glass and plastic laminate (with two air-space layers). The bullet hit the sample 4 1/2 inches from the left edge and 3 inches from the bottom. The bullet penetrator broke inside the sample, but did not penetrate it. Portions of the penetrator <u>may</u> have exited 3 1/2 inches from the left edge, 9 inches above entrance hole, 2 inches deep into the sample. No spalling occurred.

In sum, Test two identified two varieies of transparent armor that would resist .50-caliber armor piercing (AP) rounds and one that would do so without spalling. The third test also indentified a sample that would resist penetration and spalling.

The researchers designed the third prototype to increase visibility and reduce the physical effort required to open and close the hatch. The third prototype (Figure 3) was 56 inches long by 32 inches wide at the base, with a center height of 12 1/2 inches above the plane of the hull. This prototype provided a 45-degree obliquity for the transparent armor surfaces.

Prototype three was significantly different from earlier designs. A lid was integrated into the hatch, which reduced the total amount of weight a soldier has to lift to gain access to the TOW missile launcher. In addition, the viewing surface was divided into a number of easy-to-replace panes. This change came about as a result of testing which showed that the ballistic glass cracks when hit and obscures large areas of the viewing surface. During production of the prototype, however, the manufacturers made unilateral design changes, reducing the size of each piece of armored glass and bordering each of the pieces in a frame constructed of four-inch-wide steel bands. As a result, visibility from the hatch was reduced, but the information learned from developing the third prototype enabled the researchers to define improvements that will create a transparent cargo hatch suitable for on-vehicle testing.

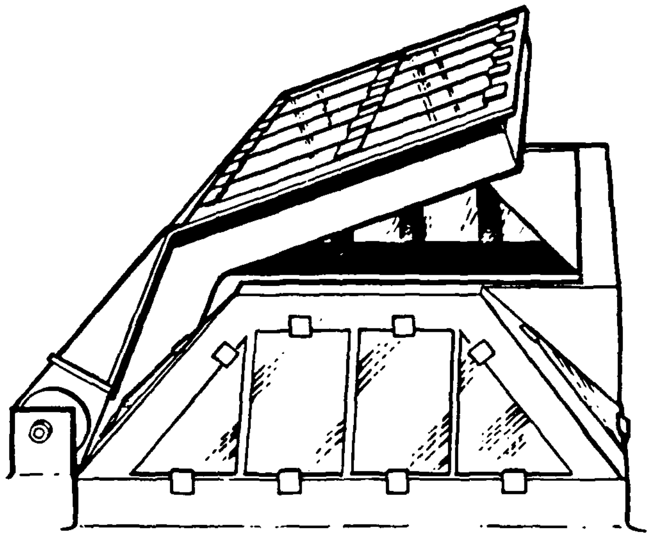


Figure 3. Third prototype hatch cover.

Because of time limitations, the fourth prototype that had been planned was not built. A schematic of this latest redesign is shown in Figure 4.

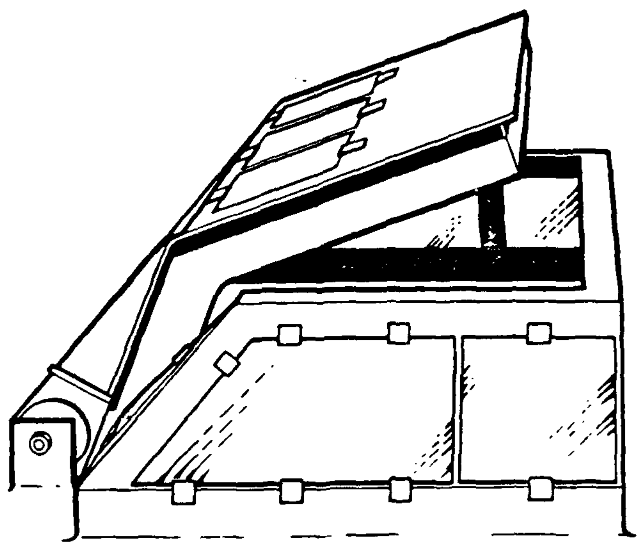


Figure 4. Fourth prototype hatch cover.

Prototype four, although untested, has been designed as a practical solution to the weight and visibility concerns. This latest design substitutes aluminum armor (approximately 22 pounds per square foot) for transparent armor in portions of the hatch where visibility is obstructed by the turret. It increases the obliquity of the transparent armor on the sides of the hatch to 45 degrees which, while adding ballistic protection, reduces weight by allowing

for the use of lighter transparent surfaces (with more polycarbonate components). In addition, prototype four reduces the workload associated with opening and closing the hatch by adding hydraulic lift devices and eliminating the visual obstruction caused by the current torsion bar and spring. Together, these changes should provide a practical solution to the weight problem.

In conclusion, the investigation yielded a transparent cargo hatch design that appears to improve visibility from the BFV's troop compartment markedly and transparent armor samples capable of stopping .50-caliber (AP). And although the 14.5-mm requirement was not met, the data strongly suggest that transparent armor with acceptable ballistic qualities can be manufactured. Undoubtedly, further investigation is warranted and should be pursued.

AN ON-BOARD AMMUNITION STOWAGE CONTAINER FOR THE BRADLEY FIGHTING VEHICLE

The M2 BFV carries 900 rounds of 25-mm ammunition when loaded for combat. Of these 900 rounds, 300 are linked and placed in a ready box in the turret. The remaining 600 rounds are stowed in 20, M621 shipping containers on shelves along the sides and under the floor of the troop compartment. These 50-pound, M621 containers are difficult to handle, open, and close. Linking rounds from M621s to reload the 25-mm ready box requires BFV soldiers to complete 21 operations, but completing these operations and preparing the stowed ammunition for reload within the crowded troop compartment is an awkward and time-consuming task.

We began work on a possible solution to the ammunition stowage and reload problem (Rollier, Salter, Graber, et al., 1988) when questions arose as to the ability of the BFV to survive hits sustained on ammunition stored within the troop compartment. Recent Army tests had indicated that the practice of stowing ammunition containers above the one-meter line, along the interior walls of the troop compartment, constituted a danger to the crew. The tests also had shown that these containers are more prone to penetration by enemy fire that could cause secondary explosions. Given these findings, the researchers anticipated that ammunition stowage above the one-meter line would become unacceptable. Because half of the prototype stowage containers we had developed for the BFV would have been stowed above the one-meter line on sponsons next to the bulkhead (outer vehicle wall), testing was suspended, and we re-evaluated the options for ammunition stowage.

This section summarizes the subsequent activities of the researchers to find a solution to the problem of stowing ammunition for the Bradley Fighting Vehicle's (BFV) 25-mm cannon. A more detailed account of the investigation can be found in Rollier, Champion, and Roberson (1987).

The researchers began the investigation by defining the requirement for a troop compartment ammunition stowage container. These requirements were (1) to reduce vulnerability to enemy fire by placing stowed ammunition below a line one meter above the ground, (2) to provide a minimum capacity of 300 rounds (one complete reload) of 25-mm linked HE and AP ammunition, (3) to simplify system configuration to permit completion of reloading tasks by fewer individuals during combat, (4) to simplify system configuration to reduce training requirements, (5) to simplify system configuration to reduce time required to reload, and (6) to modify the system configuration to reduce the number of ammunition linking operations that must be performed by the unit.

We also realized that the stowage container would have to have seats on top, a hinged lid for easy reloading, and hinged doors at the turret end to allow a direct feed into the reload box.

To arrive at an optimal design for the stowage container, we pursued an evolutional approach to this problem that involved designing and building a series of prototypes. Eventually, three prototypes were designed and two built. The prototypes that were built were evaluated in vehicles and by

subject matter experts (SMEs) and subsequently were modified. Each of the prototypes designed by the researchers incorporated features that previous observations and investigations suggested would enhance utility.

Testing of the first prototype in a vehicle demonstrated the practicality of the concept. Because BFV personnel could link all rounds in advance, they were able to load rounds into the ready box with ease. However, both the experiences of the researchers and comments from SMEs pointed up the need for modification of this design. The container's weight (354 pounds) proved excessive. The container's double-walled construction took up valuable space that could otherwise have been used for storage.

Based upon this analysis, the team designed a second, single-walled prototype. The second prototype contained the same number of rounds as the first, but was over three inches narrower and one inch shorter. Its lighter overall weight (128 pounds) was an asset both in placing the container in the BFV and in lifting the top to replenish the ammunition. The researchers experimented with placing seat pads on top of the cover and drilling into the box to install safety belts, which would secure the two individuals seated on the cover. However, the team determined that without a back support, the soldiers sitting on the container would experience severe discomfort and even possible injury during rough terrain driving. Coordination with representatives of the Human Engineering Laboratory also revealed that use of this prototype would place the individual's head too close to the top of the troop compartment.

Work on the first two prototypes provided us with enough information to develop a design for a third stowage container that conformed to anthropometric and military specifications (Figure 5). Unfortunately, the researchers were unable to construct a prototype from this design for experimentation because of time constraints on the project.

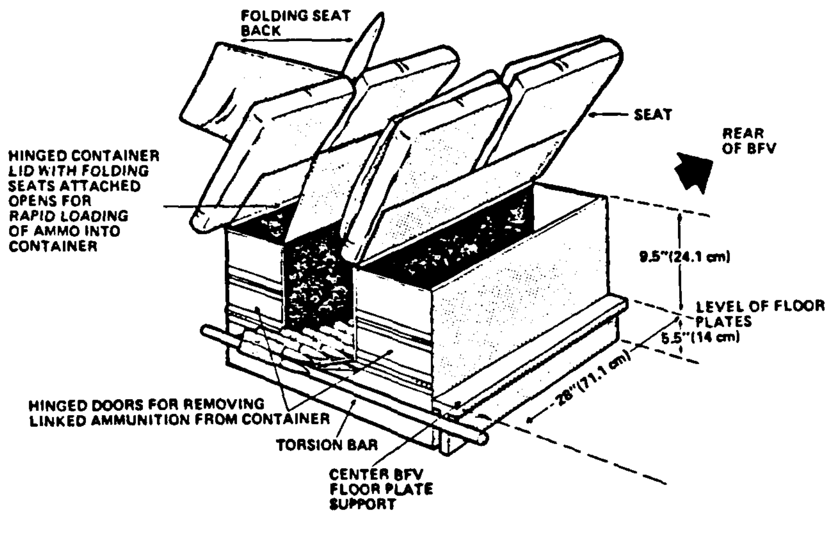


Figure 5. Third prototype ammunition stowage container.

Although the third prototype has yet to be built, its design plans do provide enough information for the researchers to make a preliminary evaluation of how functional the prototype will be. The design for the third prototype conforms to the height specifications established for individuals when seated within the troop compartment of the BFV. It also satisfies the stated objective of having ammunition stored within one meter of ground level. The four seats placed on top of the container will provide as much stability, support, and comfort as the current seats. Limited testing also indicates that individuals assigned to these seats have the same degree of access to firing ports as in current locations. The hinged doors at the end of the container closest to the turret shield door will allow BFV soldiers to move the already linked rounds into the turret ready box quickly. If the stowage container is constructed of quarter-inch aluminum sheets, it will have a manageable empty weight of approximately 150 pounds. The three compartments will store a total of 310 rounds of ammunition and permit the unit to exercise flexibility in determining the mix of AP and HE munitions to be carried.

There is an obvious need for construction of a prototype, and we recommend that a prototype ammunition container with dimensions and design as depicted in Figure 5 be constructed and tested. The prototype will allow researchers to test seat placement on the top of the container, validate procedures for placing ammunition within the container, determine specific techniques for reloading the ready box, and assess the strength and durability of the container. The concept appears to be sound and provides an ammunition storage system that permits internal ammunition storage while avoiding the survivability risks associated with current procedures. In addition, we are confident that the third prototype, as did earlier versions, will reduce the time required for reload and will reduce the number of military personnel who must participate in the reload process. Together, these benefits will significantly promote the potential for combat success.

A MODIFIED PIN FOR THE BRADLEY FIGHTING VEHICLE'S 7.62-MM COAXIAL MACHINE GUN MOUNT

The 1st Battalion, 29th Infantry at Fort Benning, Georgia, lost approximately 50 coaxial machine gun mount pins (NSN-1005-01-183-0710) during one six-month period. The 1/29th requested an investigation of this problem for three reasons. First, BFV soldiers cannot use the M240 coaxial machine gun if the mount pin is missing. Second, BFV soldiers cannot readily obtain replacements through the supply system. Last, pin loss eliminates the effectiveness of the coaxial machine gun for combat and institutional gunnery and tactical training.

After investigating the problem, we concluded that the current pin design (Figure 6) is faulty. The security cable often becomes looped around the retaining clip as the gun rotor is either elevated or depressed. This entanglement bends the retaining clip back and can pull the security cable ring from the turret fire wall. Under these conditions, the pin falls out of the machine gun mount and drops through the plenum chute.

The purpose of this investigation was to develop a cost-effective design that will reduce or eliminate problems associated with the current 7.62-mm coaxial mount pin.

The researchers developed a new design for the forward mount pin and had a local firm produce prototypes (Figure 6). The new pin is slightly smaller in diameter than the current pin and does not have a retaining clip, but rather a spring-loaded ball near the tip. Both pins have a ring in the base for a security cable and a steel washer around the stem that acts as a stop.

We provided the 1/29 Infantry with 47 of the prototype pins in order to monitor the impact of the new equipment on the readiness of the 7.62-mm machine gun. After two months, the researchers asked BFV vehicle and maintenance personnel to compare the performance of the current pin with the modified pin. They indicated that the modified pin is easier to install and more reliable; and, most importantly, they did not report losing a single prototype pin.

During the investigation, the researchers noted that newer BFVs have a redesigned coaxial mount that eliminates the mount pin problem described here. However, approximately 106C vehicles still have the current mount (turret serial number 2100 or later). These older BFVs will not undergo modification until returned to depot for rebuilding. Given the current rebuild schedule, the defective pins will be in the system for several more years.

The current coaxial mount pin is unreliable and causes a significant reduction in BFV readiness. This problem is so widespread among BFV units that coaxial mount pins are often in short supply. The modified replacement pin has proven easy to install and extremely dependable in limited testing. In addition, the modified pin is cheaper to manufacture than the current pin because of its simpler design.

Figure 6. Design comparison of coaxial machine gun mounting pins.

We recommend that U.S. Army Infantry School (USAIS) Directorate of Combat Development (DCD) endorse and support the proposal for adoption of the new pin.

A CONCEPT FOR A SILENT AUXILIARY GENERATOR
AS A SECONDARY SOURCE OF POWER FOR THE BRADLEY FIGHTING VEHICLE

The Bradley Fighting Vehicle (BFV) is often required to undertake silent watch missions where the primary objectives of the unit are to detect the enemy by any and all means possible while remaining undetected. One of the key systems available on the BFV for surveillance is the thermal sight, which enables the gunner or commander to detect the enemy at night and under limited visibility conditions.

The thermal sight is powered by the BFV's batteries when the engine is not running and is a significant drain on this power source. To ensure that the BFV is ready for immediate action, the batteries must be kept charged by constant engine idling or, if operating while noise discipline is in effect, by starting the engine at regular intervals to recharge the batteries with the alternator. Maintaining battery power in this fashion is undesirable for two reasons. Idling the engine during a silent watch mission breaks noise discipline (the engine of the BFV can be heard at a distance of approximately 2 kilometers {depending on atmospheric conditions}). Second, idling the engine creates a source of heat that is thermally detectable. The researchers concluded that if the engine could be bypassed, these two sources of detectability could be virtually eliminated.

We surmised that an alternate source of electrical power (an auxiliary generator) could eliminate the need to start the engine to charge the vehicle's batteries. The researchers proposed that the generator would enhance noise discipline and operational effectiveness, reduce the likelihood of vehicle detection by the enemy, and provide the vehicle with the ability to respond immediately when necessary. In addition, we proposed that the generator would have sufficient power to provide support turret systems including weapons, radios, and other auxiliary equipment while in the silent mode.

We surveyed national and regional manufacturers to determine the availability of a suitable generator. In each case, the researchers evaluated candidate generators against the following criteria. The generator must be as silent as possible but in no case be louder than BFV systems that it will be required to operate when the engine is not running (ISU coolers are assumed to be the loudest); must be able to maintain or charge/recharge the 24-volt vehicular and turret battery system; must provide sufficient electrical power while charging/re-charging the batteries to continue to operate all necessary vehicular systems including turret, weapons, ISU, and radios; must be mountable internally to the vehicle to provide weather and armor protection and assist in noise attenuation; must be accessible for and require only simplified repair or replacement; must claim little or no additional space in the vehicle interior; must provide at least 300 amperes peak and 100 amperes constant power; and must be cost effective.

As a result of the survey, the researchers looked at a wide variety of portable generators to provide the necessary turret and ISU electrical power. Unfortunately, the researchers found these off-the-shelf products to be too

bulky, noisy, and hot (e.g., thermally detectable) to meet the specifications outlined above.

We discovered during the survey period that a vendor already funded under an Army R&D contract is producing a prototype hybrid nuclear, biological, chemical (NBC) collective protection system for the BFV that includes as one of its components a silent turbo-alternator (Figure 7). The turbo-alternator is currently scheduled for application to the BFV as part of the NBC system during a Block III modification (around 1991). An initial investigation by team members indicated that this turbo-alternator might meet the criteria for silent operations.

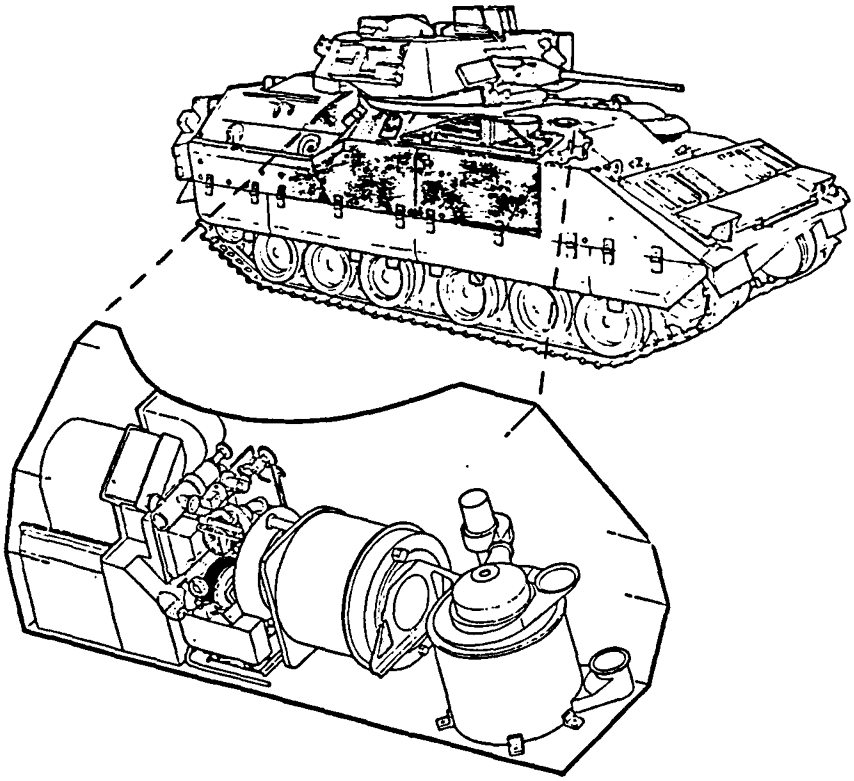


Figure 7. BFV turbo-alternator with NBC system.

Representatives from this vendor were contacted and they visited Fort Benning during 1986 to present a briefing on their turbo-alternator (silent generator). On a return visit to the vendor, the researchers investigated the ability of the vendor to connect the turbo-alternator to the turret power supply and the control panel of the NBC system. As a result of these visits and consultations, the researchers concluded that this connection can be made by using the toggle switch originally intended for the NBC filter bypass mode (no longer required by the Army). This connection will provide an electrical power only mode for use during silent watch and can also be used during periods in which the NBC system is not required.

We believe that this innovative source of electrical power can be obtained from this or any other vendor capable of turbo-alternator production and could be provided at no additional cost to the BFV program above those costs already associated with the NBC system. In fact, the vendor estimates that elimination of other BFV hardware such as the muffler, ventilator blower, and turret batteries together with the reduced engine running time for the BFV may well result in life-cycle cost savings for the BFV program while providing BFV units the silent watch capability they urgently need.

Although further research is required by the vendor and the Army, we are most encouraged by the perceived benefits of this small but powerful generator (Figure 8). Designed to power the NBC system, the generator will produce 2 kilowatts (KW) of electrical power (3 KW are easily obtainable). Three KW of electrical power is sufficient to run not only the NBC system, but the ISU and all other electrical equipment in the BFV's turret.

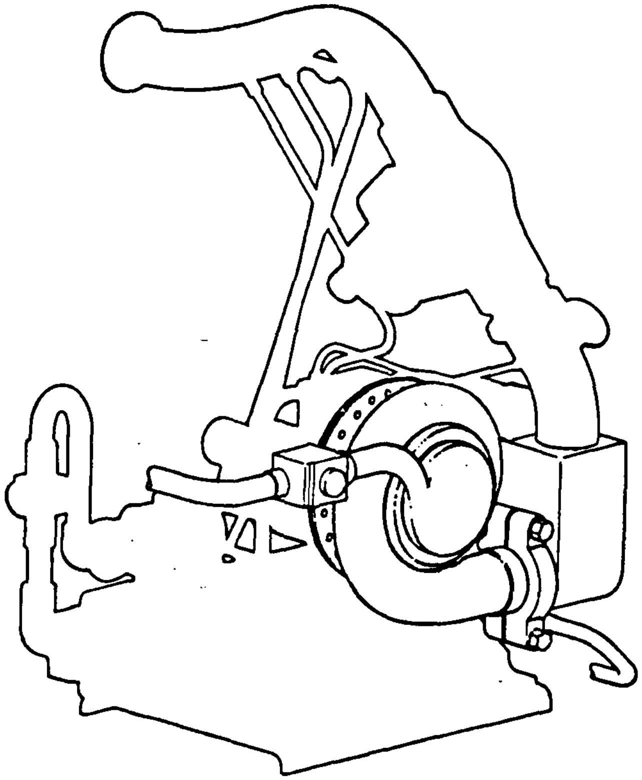


Figure 8. Prototype turbo-alternator.

The U.S. Army Infantry School (USAIS) has expressed a great deal of interest in this system. The researchers anticipate that development can be accelerated and prototypes can be obtained in the future. In the interim, USAIS has completed a modification to the BFV materiel need (MN) statement to include the requirement for silent operations capability.

Research into an alternative source of power for the BFV revealed that:

- The silent auxiliary generator concept is valid
- The technology is available
- Vendor(s) are willing and capable of pursuing the concept to completion

Because the silent generator will greatly increase the readiness of BFV units, we recommend that:

- Further research and testing should be conducted as prototypes become available
- USAIS complete coordination of the BFV requirements document to ensure that the need for a silent auxiliary generator is recognized and funded

REFERENCES

BIFV range card. (1986). (Unpublished Army Research Institute Material).

BIFV scanning techniques. (1986). (Unpublished Army Research Institute Material).

BIFV thermal operations. (1986). (Unpublished Army Research Institute Material).

Champion, D. F., Roberson, P. R., & Lewis, D. L. (1988). Developing a driver alert system for the Bradley Fighting Vehicle (ARI Research Note 88-73). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A199 023)

Champion, D. F., Rollier, R. L., Frederick, D. P., Roberson, P. R., & Knapp, S. D. (1988). Increasing the combat effectiveness of the Bradley Fighting Vehicle: New and modified thermal training procedures and products (ARI Research Report 1518). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Champion, D. F., Rollier, R. L., Knapp, S. D., & Lewis, D. L. (1988). Modification of selected integrated sight unit (ISU) controls (ARI Research Report 1519). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

FM 7-7. The mechanized infantry platoon and squad (APC). (1985). Washington, DC: Department of the Army.

FM 17-12. Tank gunnery. (1977). Washington, DC: Department of the Army.

FM 17-95-1. Cavalry for rangers. (1977). Washington, DC: Department of the Army.

FM 21-75. Combat skills of the soldier. (1984). Washington, DC: Department of the Army.

FM 23-1. Bradley Fighting Vehicle gunnery. (1986). Washington, DC: Department of the Army.

FM 23-9. M16A1 rifle and marksmanship. (1974). Washington, DC: Department of the Army.

Frederick, D. P., Rollier, R. L., Champion, D. F., Roberson, P. R., & Knapp, S. D. (1987). Developing a transparent cargo hatch for the Bradley Fighting Vehicle (Draft ARI Research Report). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Rollier, R. L., Champion, D. F., & Knapp, S. D. (1987). Using synthetic materials for thermal camouflage (Draft ARI Research Report). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Rollier, R. L., Champion, D. F., & Roberson, P. R. (1987). Developing an on-board 25-mm ammunition storage container for the Bradley Fighting Vehicle (Draft ARI Research Report). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Rollier, R. L., Champion, D. F., Roberson, P. R., & Graber, J. G. (1988). Procedures and guidelines for thermal imaging (ARI Research Product 88-39). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Rollier, R. L., & Frederick, D. P. (1987). An optical range-finding device for dismount elements of the Bradley Fighting Vehicle (Draft ARI Research Product). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Rollier, R. L., Salter, J. A., Graber, J. G., Roberson, P. R., Harbin, K. W., Wilkinson, C. S., Morey, J. C., & Salter, M. S. (1988). Bradley Fighting Vehicle system combat effectiveness: Evaluations of developments in tactics, training, and equipment (ARI Research Note 88-116). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Rollier, R. L., Salter, M. S., Perkins, M. S., Bayer, G. C., Strasel, H. S., Lockhart, D. C., Kramer, A. J., & Hilligoss, R. E. (1988). Review and analysis of BIFV operations under all visibility conditions (ARI Research Note 88-119). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

STP/21-1. The soldier's manual. (1985). Washington, DC: Department of the Army.

Thompson, T. J. (1982). Range estimation training and practice: A state of the art review (ARI Research Report 1333). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A132 616)

APPENDIX

DETAILED INSTRUCTIONS FOR THE PROPOSED STANDARDIZED RANGE CARD

WEAPON ____

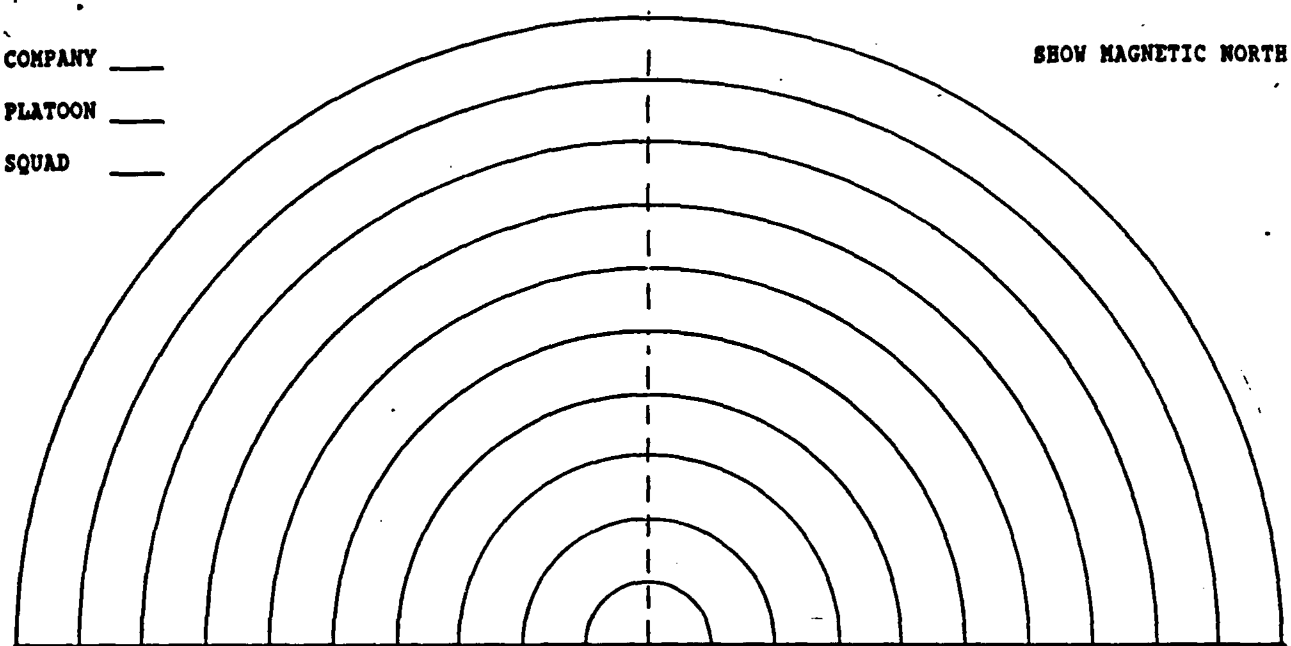
COMPANY ____

PLATOON ____

SQUAD ____

RANGE CARD

SHOW MAGNETIC NORTH



FILL IN RANGE WEAPON SYMBOL

POSITION: PRIMARY ☐ ALTERNATE ☐ SUPPLEMENTARY ☐ DTG____________

EACH CIRCLE EQUALS ____ METERS

TARGET #	DESCRIPTION	AZ / EL	RANGE / AMMO
	LL–		
	SC–		
	RL–		

REMARKS:

REMEMBER ALWAYS TO MAKE TWO RANGE CARDS. KEEP ONE. GIVE ONE TO YOUR PLT. LDR.

ABBREVIATED INSTRUCTIONS

1. FILL IN WEAPON SPACE (BFV, DRAGON, MG)
2. FILL IN CO., PLT., SQD. SPACES
3. DRAW ARROW SHOWING MAG. NORTH
4. FILL IN RANGE SPACES FOR SEMI-CIRCLES (IN METERS)
5. DRAW WEAPON SYMBOL (SEE BELOW)
6. PLACE X IN BOX TO SHOW POSITION
7. FILL IN DATE AND TIME GROUP SPACE (AS IN 211350 Jan 87)
8. FILL IN EACH CIRCLE EQUALS SPACE
9. DRAW IN LEFT LIMIT, RIGHT LIMIT
10. WRITE DESCRIPTION OF LEFT LIMIT, SECTOR CENTER, RIGHT LIMIT
11. WRITE DESCRIPTION OF EACH REFERENCE POINT
12. FILL IN AZ/EL IN MILS OR DEGREES TO REFERENCE POINTS (ALL BFV ELEVATIONS ARE WITH RANGE INDEX OF 12, AP)
13. FILL IN RANGE TO REFERENCE POINTS IN METERS
14. FILL IN AMMO SELECTED
15. FILL IN TARGET NO. FOR EACH REFERENCE POINT
16. DRAW DEAD SPACE USING DIAGONAL LINES
17. DRAW MAXIMUM ENGAGEMENT LINES

Note: Sketch terrain using standard map symbols shown below.

COMMON MAP SYMBOLS

Building

School

Church

Barn/Shed

Windmill

Cemetery CEM

Tower

Telephone Line _TEL_

Mine/Quarry

Railroad (Single)

Railroad (Multi)

Bridge

Dirt Road

Improved Road

COMMON WEAPON SYMBOLS

BFV

M113

Mortar:

81-mm

4.2-inch

120-mm

Tank: M60, M1

Machine Gun

TOW

Dragon

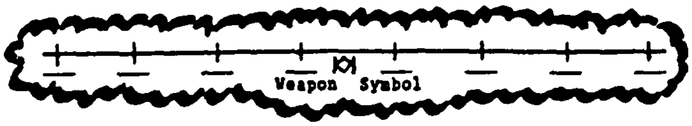
Your range card is your insurance policy! Making a good range card requires you to do three things. You must complete an accurate and detailed sketch of the terrain in your sector. You must fill in reference points which are easily identifiable through both day and night sights. And you must accurately estimate range. These three actions will ensure a high percentage of first round hits. Follow the detailed instructions given below. Carefully fill in your range card to be successful.

DETAILED INSTRUCTIONS

WEAPON. Fill in the Weapon line with the abbreviated name of your weapon.

If you are using multiple capability weapon systems (like the BFV), insert the abbreviated name of that system.

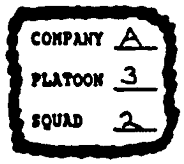
WEAPON SYMBOL Draw the symbol for the weapon or system you are using in the space above the words Weapon Symbol.



SHOW MAG. N Insert an arrow to indicate the direction of Magnetic. North.

Be sure your range card is oriented to the center of sector of fire before drawing the arrow.

CO., PLT., SQD. Fill in Company, Platoon, and Squad lines with your abbreviated designation.



DO NOT IDENTIFY YOUR BATTALION OR ANY HIGHER HEADQUARTERS

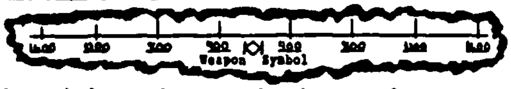
DETAILED INSTRUCTIONS

EACH CIRCLE EQUALS

Divide the range of your longest range weapon by 10. Round off this number to the next highest hundred to determine the interval of your circles.

For example, the TOW II has a range of 3750 meters. Divided by 10 this equals 375. Rounded to the next highest hundred, 375 rounds up to 400.

Fill in your Each Circle Equals line with the interval distance.



Next fill in the tick marks at the base of every or every other semi-circle with even multiples of the interval distance number until maximum range has been equalled or exceeded.

DTG

Fill in the date and time group (DTG).

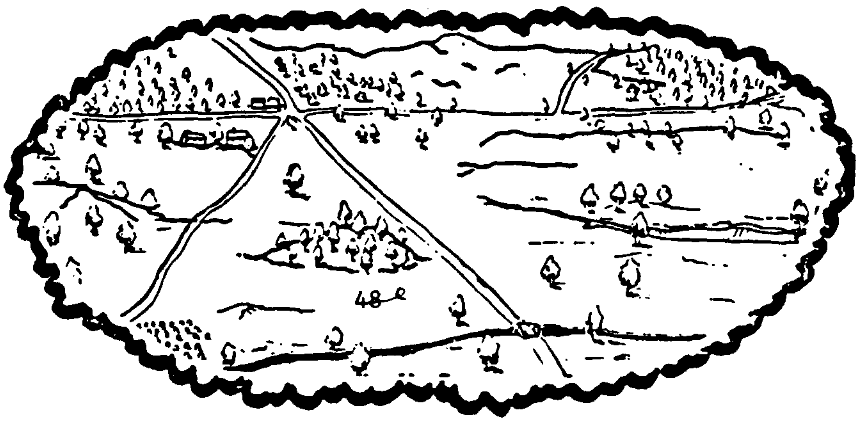
POSITION

Place an X in the box next to either Primary, Alternate or Supplementary.

This shows the type of position you have prepared the range card for.

SKETCHING THE RANGE CARD

Look carefully at the sector you are going to sketch. Now imagine that you are sitting on a very tall hill looking down at this area. This image will help you fill in terrain and features you can not actually see.

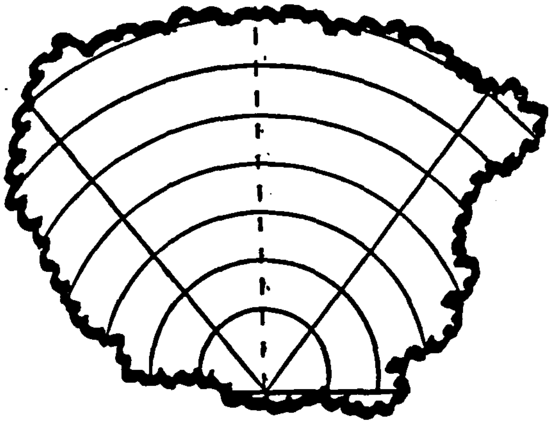


DETAILED INSTRUCTIONS

You are now ready to begin sketching your range card. Remember to use a map if one is available.

DRAWING LIMITS

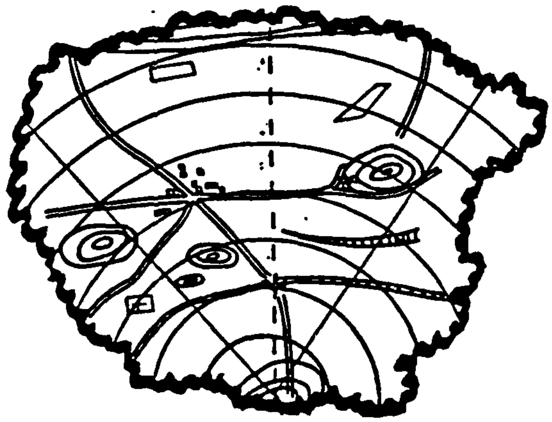
Use the dotted center of sector line on your range card to divide your sketch evenly and maintain your perspective.



Draw your left limit (LL) and right limit (RL) lines.

DRAWING FEATURES

Draw the most prominent features in your sector (bridges, roads, large buildings and streams are examples). Use standard symbols shown on the back of the range card.

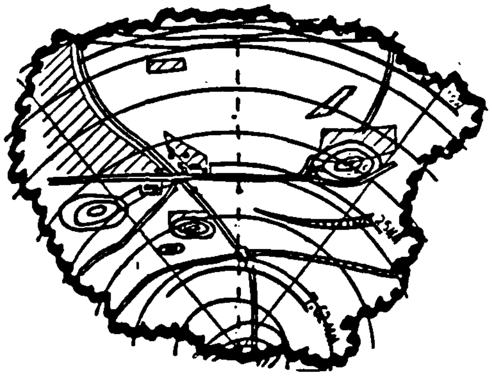


Fill in appropriate detail to link these features together (orchards, woodlines, power lines).

DETAILED INSTRUCTIONS

DEAD SPACE

Outline areas of dead space. Draw diagonal lines through the outlined areas to designate dead space. Reverse side of hills, backs of buildings, and wooded areas which cannot be seen or hit by your weapon are dead space.



MAXIMUM ENGAGE-MENT LINES (MELs)

Draw MEL(s) for your weapon(s). MELs are drawn to indicate either the maximum effective range of your weapon(s) or the maximum range at which you have been authorized to engage the enemy. If your MEL passes through dead space, then draw the MEL on the side of the dead space nearest to you.

FINISHING THE RANGE CARD

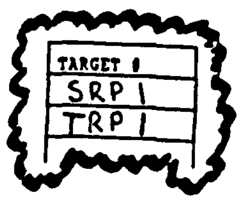
You are now ready to complete the bottom half of your range card. Describe your sector, the location of key terrain features, and all reference points.

REFERENCE POINTS

Reference points allow you to identify the location of key points in your sector. Your platoon leader may provide you reference points called Target Reference Points (TRPs). You and your squad leader may also pick reference points called Squad Reference Points (SRPs). If you have thermal sight capability, it is extremely important for you to use the sight's thermal mode to identify as many of these TRPs and SRPs as possible.

TARGET #.

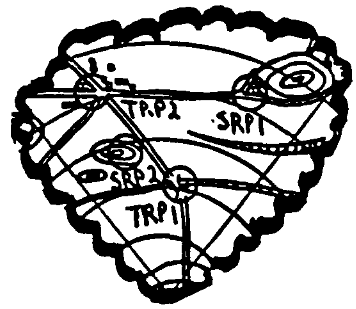
Fill in the target # column with the designation for each reference point.



DETAILED INSTRUCTIONS

TRANSFER REFERENCE POINTS

Transfer your TRPs and SRPs to the sketch.



DESCRIPTION

Describe your left limit (<u>LL</u>), sector center (<u>SC</u>), and right limit (<u>RL</u>) next to the preprinted letters in the <u>description</u> column. This action will assist you in finding other reference points.

DESCRIPTION
LL Road intersects @ 2800 m
SC Bridge 950m, Road 1650m, Hill 3200m
RL Road at edge of hill @ 2100 m

Describe your TRPs AND SRPs in the <u>description</u> column.

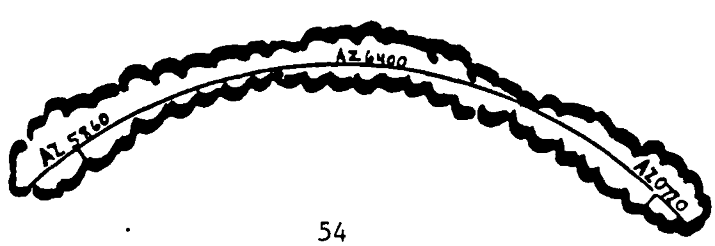
AZIMUTH

Write in the azimuth (<u>AZ</u>) and elevation column the <u>AZ</u> of your reference points. Depending on your weapon, express <u>AZ</u> in mils or degrees.

AZ / EL
5860
6400
0720

TRANSFER AZIMUTH

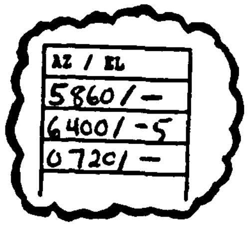
Transfer your <u>AZ</u> settings for your left limit (LL), sector centor (SC), and right limit (RL) to your range card.



DETAILED INSTRUCTIONS

ELEVATION

Write in the azimuth and elevation (EL) column the EL of your reference points. Depending on your weapon, express EL in mils or degrees. If your weapon does not have an elevation setting, leave EL blank. When using the BFV's integrated sight unit to determine elevation, select 12 (battlesight zero) on the range index and AP prior to reading the scale.

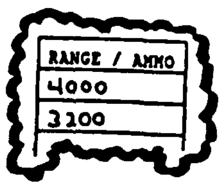


FINDING RANGE TO TARGETS

Use the most accurate method available to you. A laser range finder is the most precise. Stadia lines on your weapon's sight or binoculars are relatively accurate when combined with the WORM formula and good terrain interpretation. Field expedient methods such as the tracer burn out and the hundred meter method may be used. If you have a map, use it to assist you in estimating range.

RANGE

Write in the range and ammo column the distance in meters from your position to each reference point.



AMMO.

Write in the range and ammo column the ammo you have selected as being most appropriate for each reference point.